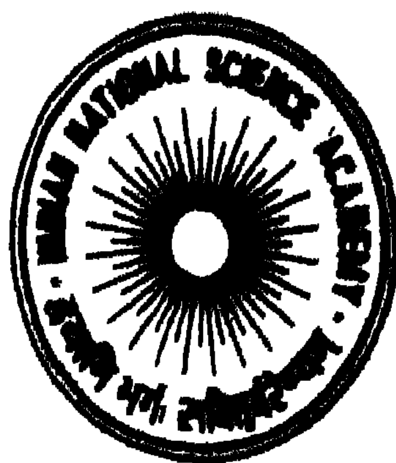


HISTORY OF TECHNOLOGY IN INDIA

Vol.I

Editor
A. K. BAG



INDIAN NATIONAL SCIENCE ACADEMY
NEW DELHI

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Vol I

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From Antiquity to c. 1200 A.D.

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INDIAN NATIONAL SCIENCE ACADEMY
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FOREWORD

There is ample testimony for the emergence and evolution of several advanced large human settlements from about 2500 BC in the Indian sub continent from a variety of artifacts testifying to creativity and skills in areas of agriculture, water management, animal husbandry, construction, tool making, textiles, fired clay pottery, carved stoneware, smelting for metals, alloys and shaped materials for transport, weapons as well as jewellery, decorative objects, toys and instruments for music & games. Natural materials, living renewable resources as well as minerals have been processed to evolve colours, pigments, preservatives, flavours, perfumes adhesives, lubricants, protective coatings and medicinal preparations.

The availability in the last 50 years of new scientific techniques of micro analysis, spectroscopy photography, computer modelling have enabled persuit of new scientific studies and for precise definition of dates, origin and nature of materials, simulation of processes.

The Indian National Commission for the History of Science functioning in the Indian National Science Academy has embarked on the major mission of preparation of a four volume History of Technology in India. The Commission has mobilised several scholars in many disciplines of social, historical, physical and biological sciences for authoritative articles and chapters. I am happy Volume I covering the period from antiquity to 1200 AD, has been completed and is now ready for publication. The other volumes for the periods 1200—1800, 1801—1947 and 1947 to the present time are being planned and of these, volume III for the period 1801—1947 is in its final stages.

These volumes resulting from sustained research, critical assessment of knowledge from several sources, with tables, photographs, sketches and references to sources are very valuable documents.

The Indian National Science Academy is deeply grateful to the authors and editors for their painstaking and scholarly contribution to this volume. The services of the Members of the Indian National Commission for the History of science and the Members of Advisory Boards are much appreciated. These volumes will undoubtedly fulfil long felt aspirations and will become major reference sources to scholars and the public all over the world.

(S. VARADARAJAN)
Chairman,
Indian National Commission for
History of Science
and President
Indian National Science Academy

INTRODUCTION

Each age has its own technology and the technology carries the stamp of its age. This is a well-known dictum. But this two-way relationship between society at any epoch and its technology, becomes meaningful only when each topic is taken by itself and linked with other areas of technology upon which it was dependent or the age in which it was developed. This approach has not always been made possible since in ancient times there was as such no strict boundary of regions, and material techniques moved with movement of people, through trade, commerce and for livelihood. The modern specialists, on the other hand, are mostly bound by their individual speciality, age, and sometimes their individual country. Availability of document and their exact decipherment are problems to this kind of approach. In a book of technology, the technical details are also of primary importance. Keeping these in mind the series was restricted to technology of Indian subcontinent only based on the survey of literary sources, archaeological reports and materials of different periods and dynasties, and studies made on them from time to time.

The volume contains contribution of thirty Indian experts and begins with Stone Age and Bronze Age technologies to have some idea of the Indian subcontinent in global context. Various Prehistoric cultural terms like Paleolithic, Mesolithic, Neolithic, Bronze Age etc. are used in Indian context following European and Mediterranean cultures. There is abundant evidence of Stone Age cultures from the time of Pleistocene and these have been described as early, middle and late Stone Age on the basis of major type of Stone industries found in Soan and Beas Valleys (Punjab & Himachal Pradesh) and river of Narmada (Adamgarh, Jabalpur area, Bhera Ghat, Barasimla, Maheshwar etc.), Krishna Bridge, Ganga & Sone valleys (Barkaccha, Sidhpur, Lekhand etc.) and other places around Bombay and Madras. The fashioning of Stone Age tools and techniques, indicates that there was a continuous struggle by prehistoric man for survival which changed skills of fashioning of crude pebbles or lithic tools stage by stage. The next phase of Neolithic culture is marked by some kind of mixed farming, domestication of animals, use of potteries, building of dwelling houses etc, in which the stone is still the basic material of protection.

The Bronze (copper + tin) is found in use in Indian subcontinent at quite an early phase and became a distinctive feature of the Indus Valley Culture (Harappa, Mohenjo-daro, Chanhu-daro & other sites). The materials known to the Indus Valley people are gold, silver and copper in alloy with tin (bronze) and with arsenic and lead. From 200 sample analysis, it is found that 23% copper was alloyed with tin, 12% with arsenic and 5% with lead. Tin and arsenic alloy (with copper) were common with Harappan culture whereas tin alloy (with copper) were exclusively used in post-Harappan Banas, Jorwe and other Chalcolithic cultures. The varied range of copper and bronze implements, weapons and house-hold utensils point to

large exploitation of metals and flourishing industry of mining, metallurgy and manufacturing trade. Harappan culture witnessed a remarkable standarization of ceramics, brick sizes, both burnt and mud bricks. The skill of brick layers is visible in great public buildings of the citadel complexes, great bath of Mohenjo- daro and granaries of both Mohenjo-daro & Harappa. There is ample evidence of agricultural activities, textiles, town planning, fabrication of houses, domestication of animals, transportation, arts & crafts attesting the antiquity of many other organised technical activity in later times in which India was well-known. What is that supported this vast technological, economic and social activities ? Is it surplus agriculture ? Huge brick built granaries is of course an indicator. Trade also assisted in two way diffusion of culture and technology.

Ṛgvedic civilization (c.1500 - 1000 B.C.) has been underrated by few paradigms like Aryan invasion, rural civilization (with reference to urban Harappan civilization), absence of cosmic order *(ṛtam)* including scientific spirit. These criticisms are not found meaningful. These get added significance when examined against a backdrop of high monistic order, civil war of oppressed agriculturists living in Haryana & Punjab, semi-urban surroundings of people living side by side and other factors. Iron-use got slowly a new lease of life in Karnataka in South U.P.,Rajasthan area in Ahar,Atranjikhera (c.1150 B.C.), and West Bengal - Bihar area in Pandu-rajar Dhibi & Barudih (c 1200 B.C.). This led to some kind of urbanization and power struggle and a complex process of class structure. Originally there was division of labour but no institution of caste. Gradually the impact of caste system categorized people as well as metals, woods and even mundane things into castes and subcastes, a stigma for free exchange of knowledge. The revolt against tradition and conservatism brought in many new ideas and new pursuits. The period from c. 1000 B.C. to the beginning of the Christian era saw new technology with the vedic people. The power struggle and rivalry promoted technology further to protect and augment the power structure. Nanda and Maurya empires flourished. Rapid growth took place in mining, metallurgy, semi- precious gems and weaving industry to manage state control economy. This is clear from the *Arthaśāstra* of Kauṭilya which had prescribed duties for superintendent of mines, metals, coins and mints, ocean-mines etc. The head Superintendent of metals was entrusted to carry on the manufacture of coins, the ocean mine superintendent was for the collection of conch shells, diamonds, precious stones,pearls, corals and regulate commerce on the above activities. There is also reference to guilds of workmen and those who carry on the co-operative along with the details of manufacturing and processing techniques. The work shows unique specialization. To assess the extent of this knowledge, papers have been grouped for better understanding.

The details of copper mining from Singhbhum belt and Khetri areas, gold mining from Karnataka & Andhra, lead, zinc and silver mining from Rajasthan & Karnataka region show that these were based on traditional techniques. The quantitative analysis by modern methods of some of the metal objects available during this period testify the indigenous source on the basis of their composition, temperature at which these were made, nature of furnaces employed for the purpose, selection of raw materials etc. This furthur corroborates that the forging, lamination

and smelting techniques were undoubtedly very old. Carburization of iron was known as early as 6th century B.C. The technique of corrosion-resistant forge-welded structures is still a mystery. The methods of coin-making through punching, casting, reponse and die-struck techniques were well-known. The broad chalcolithic phase also witnessed the growth of hand-made, wheel-thrown and wheel-turned potteries with painted decorations. The BR (the Black & Red) wares of Harappan and post-Harappan sites -Lothal, Ahar, Rangpur, Prakash etc. are unique, and possibly influenced the growth of LR (Lustrous Red) wares of Saurashtra and other sites. The PG (Painted Grey) and NBP (Northern Black Polished) wares found at Atranjikhera, Hastinapur, Alamgirpur etc. are associated with Iron Age and is contemporaneous with Vedic culture (c. 1200 B.C.) in India. The glass objects were valued primarily as objects of art. The evidence of vitreous paste, frit, faience,glazed etc are evolutionary stage of glass making. The manufacturing details, colouring agents and tools used for fabrication of these materials are now fairly known. The beads, steatite beads, limestone, gypsum, alabaster, lapis lazuli, turquoise,quartz or beryl were also considered by the Indians under the categories of gems possibly for their shining surfaces and commercial interest. Intersting details are found on the classification of gems, their sources, etymology, and mining. The manufacture of such a wide varities of material objects indicates that the ancient Indians could control various degrees of heat through multi-faced ovens leading possibly to furnace technology.

Life, in ancient India was conceived as the manifestation of body, senses and spirit. People were equally prone to new fashion and decorated their own bodies, their homes, temples and gods. Effort was also made to upkeep body and mind and free it from diseases. Obviously plant and animal products got their use very early. But how early metals and metallic compounds began to be used in drugs is not known. The classical works *(Bṛhat Trayī)* have mentioned the use of mercury and metallic compounds. Later works have given explicit details of conversion techniques of mercury and metals into pharmaceutically suitable components through different alchemical processes. Sandle paste, flower and flower extracts were common as traditional cosmetics and perfumes used in temples and houses. Early works contain details of various ingredients for cosmetics, their manufacturing process and various combinations. The dyes, pigments and mordants were well-known for the colouring of textiles and painting of potteries, metallic surfaces and pictures. When the hand woven technique of textile changed with the discovery of loom, the changes both in the composition of fibers and natural dyes and their combinations became faster. Colouring materials were obtained from vegetable products of indigo *(nīla)*, lac *(lākṣā)*, turmeric *(haridrā)*, madder *(mañjiṣṭhā)* etc. Minerals like lapis lazuli, calamine ferric oxide lime, lead, blue vitriol etc. were also used. The Surgical techniques developed with the process of survival and was obviously considered as one of the important divisions of Ayurveda. The problems like peptic ulcer, perforation, paracentasis, cauterisation, blood-letting, piles and fistula, problems of stone, laparatomy, hydrocele, rhinoplasty etc were tackled. How were these operations possible in the absence of anaesthesia? The nature of operations, dressing, use of alkali of various strengths both for internal and external application, and the use of 101 blunt and 20 sharp instruments indicate that both pre- and post operative phases were taken care of.

For correct diagnosis of disease, examination of patients and diseases were recommended through different technical procedures. Clinical observations, diagnosis and cure prospered under medical profession. Critically investigative philosophy came into vogue. The therapeutic techniques for appreciating the cause and nature of the diseases with the systematic medicine through *tridoṣa* theory was a unique contribution. The soul *(ātmā)*, mind *(mana)*, and body *(śarīra)* as three components of living entities were considered very important for a holistic treatment towards patients in classical Indian medicine.

Agriculture is an old practice and ancient Indians had good knowledge of soil, seeds and sowing methods including transplantation, seasons of plantation, use of pesticide, manuring and irrigation. Post-harvest operations of crops, for consumption like grinding, pounding, winnowing, domestic operation like baking, firing, grilling, steaming, cooking under pressure, churning butter and kitchen utensils etc were common. The *Soma* juice and other fermented drinks with details of base materials, ferments and manufacturing techniques were known from ancient times.

The period from beginning of the Christian era to c. 500 A.D. saw a lot of transition through Greco-Roman influences. Mathura and Ujjayini became important trade centres. Many important texts were compiled and written. Both national and international trade helped diversification of knowledge & craft of various types and growth of some kind of urbanisation in the South.

Town-planning during this period was the part of construction including proper orientation of buildings, sanitary, drainage, temples and use of right types of building materials (stones, bricks, rocks, wood, mortars, plasters). Fortification or erection of a physical barrier against a possible danger was a common practice. The test for stability of soil before any construction of temples, and judicious selection of foundation materials were compulsory. The temples were broad based tapering to a point giving built-in stability. All activities of the construction starting from quarrying of stones of right texture, shade, consistency in sculpting, dressing, setting in proper positions and various other related works were supervised by the ancient architect. Construction of reservoirs, canals, sluices, embankments for irrigation work were common both in north and south India. Various type of water lifting devices for continuous and discontinuous water supply were recommended. The examination of roads, bridges, wells, rivers, were part of the system to meet war & domestic requirements through transportation. Animals like cattle, elephants, equines, camels etc became a part of the organized activity and veterinary science developed following ayurveda with reference to diseases, treatment, training and breeding etc. Water transportation also flourished since it was profitable and easy to move in spite of many risks.

Arts and crafts also flourised. The jewellery made of precious metals, gold, silver & other metals and gems have a special place in Indian tradition. Not only is it an asset, it increases the aesthetic beauty as well. Indian gods and goddesses are also found to have been decorated with forehead, ear, neck, arms, ankle, finger ornaments and ornaments with inlay work and studding of gems. Wooden furniture for household or other purposes were quite common for sittings, reclining, rest, and for different categories of persons and dignitaries (like Brāhmaṇas & Kings). Both

hard and soft materials like board & dust, birch-bark, palm leaves, leather, cotton, cloth, paper and ink were used as writing materials. Harder materials were mostly used for engraving and embossing. Leather, leather crafts including processing of skin and their uses, leather dresses, leather boats, boxes, parchments, drums and musical instruments were also important as part of social life. Standardisation in technical crafts and weights and measures were attempted. This is visible in units of length, breadth, area, volume, weight and also time. Indians believed always in a kind of limited & limitless universe. This is also reflected in the system. The concepts of past, present and future have also been found interesting in its various dimensions.

The Suṅga dynasty initiated fudalism and caste system rigidly. The system continued during Kuṣāṇa, Gupta and Śātvāhanas. The late Gupta ruler, Vākāṭaka kings, Bhoja, Cera & Colas continued the practice with rights for management of properties and administration which in turn introduced middlemen through system of lease. Feudal class became an organisation of exploitation and carried little responsibility to mitigate the responses from artisans and ordinary people. The Delhi Iron Pillar (c. 4th century A.D.), Konarak Temple at Bhuvaneshwar, Dhar Iron Pillar built by Bhoja (c. 1050 A.D.) represented power, technological skill and knowledge.

The volume gives an idea of some of the important technological practices that developed despite social limitations. This has created also gaps and uncovered areas for study. It is hoped that these gaps will be filled up by experts in future. The work is an out-come of a collaborative effort. The editor is concious of the difficulties for editing such a volume in which a large number of experts and their perceptions are involved. All efforts have been made to make it meaningful and interesting. The editor is indeed thankful to all the contributors for their co operation. However, he will be thankful for any suggestion for improvement. He expresses his sincere gratitude to the members of the Advisory Board (ancient period) and the Indian National Commission for History of Science for general advice and guidance from time to time. He is equally grateful to Dr. N.R. Banerjee & Prof. S.K. Mukherjee for active help & many valuable suggestions. Thanks are also due to Mr. R.N. Ghosh, Mrs Shabnam Shukla, Mrs Kiran Arora & Mr. K. Jayan of the Indian National Science Academy for their ready support in sorting out documents and all possible help. I am no less thankful to Ms. Sharmila Ghosh who has helped in the computerisation of the volume.

Editor

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Kalra, S.K.	Department of Veterinary Microbiology, College of Veterinary Sciences, HAU, Hisar 125004.
Krishna Murthy, K.	Former Professor and Head of the Department of History and Indian Culture, Sri Sathya Sai Institute of Higher Learning, 43/10A, N.R.Peta, Kurnool 518004.
Krishnamurthy, Radha	'Subhodaya', 38, Eleventh Main Road Malleswaram West, Bangalore 560055.
Mate, M.S.	Former Professor, Deccan College, 1896 Sadashive Peth, Pune 411030.
Mukherjee, B.N.	Professor of Ancient Indian History and Culture, University of Calcutta, Calcutta.
Nigam, M.L.	Former Director, Salarjung Museum, Hyderabad 500002.
Pant, Manju	Pandit G.B.Pant Government Museum, Almora 263601.
Patel, Krishna Amin	National Institute of Design, Paldi, Ahmedabad-380007.
Raman, K.V.	Former Professor & Head, Department of Ancient History & Archaeology, University of Madras, Madras.
Roy, Mira	80 B, Vivekananda Road, Ground Floor, Calcutta 700006.
Selvarangan, R.	Former Deputy Director, Leather Research Institute, 52 First Main Road, Masant Nagar, Madras 600090.
Sharma, A.K.	c/o B.R.Singh, Vice Chancellor, Bihar University, Muzaffarpur.
Sharma, Akhila Nand	Former Head of the Department of Śalya, State Ayurvedic College, Varanasi, B 36/21, Kh-2A, Kaiwalya Dham Ext., Durgakund, Varanasi 221005.
Singh, R.D.	Former Professor, Department of Mining Engineering,Indian School of Mines, 37 A, Ravindra Puri, Lane No.5, Varanasi 221005.

Singh, R.H. Professor and Head, Department of Kāyacikitsā, Banaras Hindu University, Bharat-Bharati, 6 Ganga Bagh, Lanka, Varanasi 221005.

Srinivasan, T.M. PCL Division, Indian Institute of Chem. Tech.. Hyderabad 500007.

Varadarajan, Lotika Flat No. 4A, Giridhar Apartments, 28 Ferozeshah Road, New Delhi 110001.

Vyas, R.T. Director, Oriental Institute (MS University of Baroda), Opp. Palace Gate, Palace Abad, Vadodara 390002.

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(b) Tables

ABBREVIATIONS
(Journals)

AMA	American Anthropologist
ANI	Ancient India (Bulletin of Archaeological Survey of India)
ANNORI	Annals of Bhandarkar Oriental Research Institute
ANRASI	Annual Report : Archaeological Survey of India
ANRIE	Annual Report : Indian Epigraphy
ANT	Antiquaries Journal
ANTI	Antiquity
ARC	Archaeological Society of South India
ARCH	Archaeological Survey of India
ARCHM	Archaeomaterials
ART	Artibus Asiae
ASP	Asian Perspectives
BENM	Benaras Metallurgist (Hindi)
BHAR	Bharati (Bulletin of the College of Indology
BULED	Bulletin Deccan College and Research Institute
BULET	Bulletin de Liaison du Centre International d'Etude des Textiles Anciens
BULL	Bulletin of the Directorate of Archaeology
BULM	Bulletin of the Metals Museum
BULP	Bulletin of the Peak District Mines Historical Society
BULSO	Bulletin of the School of Oriental and African Studies
CANAMM	Canadian Mining and Metallurgical Bulletin
COROL	Corolla Numismatica
CTI	Corpus Telengana Inscriptions
CULHI	Cultural Heritage of India
CUNN	Cunningham (Ed)
CURS	Current Science
EASW	East and West
EAT	Eastern Anthropologie
EI	Epigraphia Indica

ER	Epigraphical Reports
ERM	Erzmetall
EXP	Expedition
GAAD	Gazetteer of the South Arcot District
GI	Glass Industry
HERA	Hertford-shire Archaeology
HISM	Historical Metallurgy
HRAS	Hyderabad Archaeological Services
IA	Indian Antiquary
IAR	Indian Archaeology : A review
IC	Indian Culture
IF	Indian Farming
IHQ	Indian Historical Quarterly
IJHS	Indian Journal of the History of Science
IJVS	Indian Journal of Veterinary Science and Animal Husbandry
IM	Indian Minerals
IMB	Indian Museum Bulletin
INAR	Indian Veterinary Journal
IND	Indica
INPS	Inscription of the Pudukkotai State
INTES	Interdisciplinary Science Reviews
JAOS	Journal of the American Oriental Society
JARS	Journal of the Archaeological Science
JASB	Journal of the Asiatic Society of Bengal
JBIOR	Journal of the Bihar and Orissa Research Society
JBNHS	Journal of the Bombay Natural History Society
JDL	Journal of the Department of Letters
JESO	Journal of the Economic and Social History of the Orient
JHGS	Journal of the Hyderabad Geological Survey
JICS	Journal of the Indian Chemical Society
JIDH	Journal of the Indian History
JIDOA	Journal of the Indian Society of Oriental Art
JIE	Journal of the Institution of Engineers (Hindi)

JIES	Journal of the Indo-European Studies
JISI	Journal of the Indian Statistical Institute
JJNI	Journal of the Japan - Netherlands Institute
JMGA	Journal of the Madras Geographical Association
JMMF	Journal of the Mines
JMSB	Journal of the M.S.University
JNSI	Journal of the Numismatic Society of India
JOAI	Journal of Indian Art and Industry
JOI	Journal of the Oriental Institute
JRAS	Journal of the Royal Asiatic Society
JRGS	Journal of the Royal Geographical Society of India
JRSA	Journal of the Royal Society of Arts
KA	Kathan (Hindi)
LAN	L'Anthropologie
MA	Man
MAE	Man and Environment
MAI	Man in India
MASB	Memoire Asiatic Society of Bengal
MASI	Memoires of the Archaeological Survey of India
MEGS	Memoires of the Geological Survey of India
MET	Metallography
META	Metals News
MIEM	Mineralogical Magazine
MIM	Minerals and Metals Review
MINEM	Mines and Minerals
MINMA	Mining Magazine
MOAS	Modern Asian Studies
NAH	Naturalis Historia (Pliny)
NC	Numismatic Chronicle (London)
OHRJ	Orissa Historical Research Society Journal
PASB	Proceedings of the Asiatic Society of Bengal
PFPAC	Proceedings of the First Pan American Congress on Prehistory
PIAS	Proceedings of the Indian Academy of Sciences

PIHS	Proceedings of the Indian History Congress
PROPA	Proceedings of the First Pan African Congress on Prehistory
PURA	Puratattva (Bulletin of the Indian Archaeological Society)
RADCA	Radiocarbon
RGSI	Records of the Geological Survey of India
RMSI	Records of Mal. Survey of India
SBE	Sacred Book of the East
SCAN	Scan. Journal of Metallurgy
SCI	Science
SCIC	Science and Culture
SCIT	Science Today
SOAA	South Asian Archaeology
SOII	South Indian Transcriptions
SI	Steel India
SYA	Syria
TATAI	Tata Iron & Steel Company
TEB	Tebiwa
TEX	Textile History
THAR	The Anvil's Ring
THEM	The Eastern Metals Review
THGM	The Geographical Magazine
THNS	The New Sketch
TNS	Transaction of the Newcomen Soc. London
TOP	Town Planning Review
TRAP	Transaction of the American Philosophical Society
TRIIM	Transaction of the Indian Institute of Metallurgy
TRIIMS	Transaction of the Indian Institute of Metals
TRIMGI	Transaction of the Mining & Geological Institute of India
TRMGMI	Transaction of the Mineral
TRV	Travancore Archaeological Series
VES	Vetroe Silicati
WA	World Archaeology

ABBREVIATIONS (Sanskrit and other texts)

Abhi.C	Abhidhānacintāmaṇi
Abhi.R	Abhidhānaratnamālā
Ag.Pu	Agni Purāṇa
Āin	Āin-I-Ākbari
Ait.Br	Aitareya Brāhmaṇa
Ajb	Ajñānabodhinī
Akh	Akhyānakāmāni-Kośa
Amara	Amarakośa
ĀŚl	Āpastamba Śulbasūtra
AŚ	Ārthaśāstra of Kauṭilya
Aṣṭd	Aṣṭādhyāyī of Pāṇini
Aṣṭ. Hṛ	Aṣṭāṅgahṛdaya Kośa
AV	Atharvaveda
Bas	Basavarājīya
Bas.Pu	Basava Purāṇa
Bhāg.Pu	Bhāgvata Purāṇa
Bra.Pu	Brahma Purāṇa
Br.Pu	Brahmāṇḍa Purāṇa
Br.Su	Brahmasūtra
Bṛh.P	Bṛhaspati
Bṛh.S	Bṛhat Saṃhitā
BŚl	Baudhāyana Śulbasūtra
CD	Cakradatta of Cakrapāṇi
C.Saṃ	Cakra - Saṃgraha
Chānd.U	Chāndogya Upaniṣad
CS	Caraka Saṃhitā
CS.Ci	— Cikitsa Sthana
CS.In	— Indrīya Sthāna
CS.Ka	— Kalpa Sthāna
CS.Ni	— Nidāna Sthāna
CS.Śa	— Śarīra Sthāna

CS.Si	— Siddhi Sthāna
CS.Sū	— Sūtra Sthāna
CS.Vi	— Vimāna Sthāna
Cu.V	Cullavagga
Dr	Dravyapariksa
Ga.S	Gandhasāra
Gāt.S	Gāthāsaptaśati
Gau.V	Gauḍa Vāho
GSS	Gaṇitasārasamgraha
Hṣa	Harṣacarita
Kād	Kādambarī
Kā.Pu	Kālikā Purāna
Kas.S	Kāśyapa Saṃhitā
Kāt.K	Kathākośa
Kāt. Śr	Kātyāyana Śrautasūtra
Kaus.Up	Kausitakī Upaniṣad
Ki	Kirātarjunīya
Kṛ.P	Kṛṣi Parāśara
Kṛt	Krtyakalpataru
Ku	Kumāra Sambhava
Kuś	Kuśajātakam
Kuv	Kuvalayamalakatha
Lī	Līlāvatī
MB	Mahābhārata
MV	Mahāvagga
M.Ni	Mādhava Nidāna
Ma.K	Madhukosa Commentary
Mait.S	Maitrāyanī Saṃhitā
Mal	Mālvikāgni Mitra
Manu	Manusmṛti
Mat. Pu	Matsya Purāṇa
Mil	Milindapanho
Nat	Nāṭyaśāstra
Pa	Pañcatantra
Pañc	Pañcakhanaka
Pañc.Br	Pañcaviṃśa Brāhmaṇa
PB	Pāṇinikālin Bhāratavarṣa

Raghu	Raghuvaṃśa
Rāj	Rājataraṅginī
Rām	Rāmāyaṇa
Rām Ayo.	Ayodhyākāṇḍa
Rām Bala	— Bālakaṇḍa
Rām.Sund	— Sundarakāṇḍa
RHṛ	Rasahṛdaya
RNa	Rasaratnākara of Nāgārjuna
Rṇv	Rasārṇava
Rṇv.T	Rasārṇava Tantra
RP	Rasopaniṣat
RPS	Rasaprakāśa Sudhākara of Yaśodhara
RRS	Rasaratna Samuccaya .
Ṛts	Ṛtusaṃhāra of Kālidāsa
ṚV	Ṛgveda
SN	Samyukta Nikāya
Sam.Sū	Samarāṅgana Sūtradhāra
Saṅkh.Śr	Saṅkhyāyana Śrautasūtra
Sar.S	Sarvadarśana Saṃgraha
Sāraṅg	Sāraṅgadhara Paddhati
Śat.Br	Śatapatha Brāhmaṇa
Śik.S	Śikṣā Samuccaya
Śiv.R	Śivatattva Ratnākara
ŚN	Samyukta Nikāya
SR	Śilparatna
SS	Suśruta Saṃhitā
SS.Ci	— Ciktsā Sthāna
SS.Ka	— Kalpa Sthāna
SS.Ni	— Nidāna Sthāna
SS.Sū	— Sūtra Sthāna
SS.Utr	— Uttara Sthāna
Tan	Tantrakhyāyikā
Tark	Tarkasaṃgraha
TBr	Taittirīya Brāhmaṇa
TS	Taittirīya Saṃhitā
UDS	Upadesasahaśrī
Upa.Pr	Upamitibhāva Prapañcakathā

Uttar.Ti	Uttarādhāyana Ṭīkā
Va	Vaikhānsa Gṛhyasutra
Vāij	Vāijayantī
Vāj.S	Vājasaneyī Saṃhitā
Vāl.R	Vālmikī Rāmāyaṇa
Vāt	Vātsyāyāna
Vā.Pu	Vāyu Purāṇa
VP	Vinaya Piṭaka
Vi.Pu	Viṣṇudharmottara Purāṇa
Vik	Vikramorvasīyam
Vin	Vinaya Text
Vip.S	Vipāka Sūtra
Viv.Pa	Vivāha Paṭala
Vṛ.Āyur	Vṛkṣāyurveda
YR	Yogaratnākara
YV	Yajurveda Saṃhitā
YY	Yogayātrā

CHRONOLOGY OF MAJOR PERIODS AND DYNASTIES

Prehistoric Period

B.C.	c. 25000 & before	Early Paleolithic/ Early Stone Age.
	c. 25000 - 5000	*Middle Paleolithic/ Middle Stone Age.*
	c. 5000 - 3000	Mesolithic / Late Stone Age.
	c. 3500	Neolithic Age in Baluchistan.
	c. 3000	Agricultural communites in Baluchistan.
	c. 2500 - 1550	Harappa culture in Sind, Baluchistan, Panjab, Rajputana and Saurāṣṭra.

Protohistoric Vedic Period

B.C.	c. 1500 - 900	Compilation of the Hymns of the Ṛgveda in Panjab and
	c. 900 - 500	Kashmir regions.
		Later Vedas, Brāhmaṇas and early Upaniṣads in Gangetic region.

Historic Period

B.C.	c. 563 - 483	Gautama Buddha.
	c. 542 - 490	Bimbisāra King of Magadha.
	c. 490 - 458	Ajātasatru King of Magadha.
	c. 362 - 334	Mahāpadma Nanda, King of Magadha.
	c. 327 - 325	Invasion of Alexander of Macedon.

Mauryan, Kuṣāṇa and other Periods

	c. 322 - 298	Candragupta.
	c. 298 - 273	Bindusāra.
	c. 269 - 232	Aśoka.
B.C.	c. 190	Greek Kingdoms in N.W. India.
	c. 183 -147	Puṣyāmitra Suṅga.
	c. 90	Śakas invade N.W. India.
	c. 71	End of Suṅga Dynasty.
	c. 50B.C.- A.D.250	Śātvahana Dynasty in Deccan.
A.D.	Early 1st century	Kuṣānas invade N.W. India.
	c. 78.- c. 101	Kaniṣka.
	c. 130 - 388	Śaka Satraps in Ujjayini.

Gupta Period and others

A.D.	c. 320 - 335	Candra Gupta I.
	c. 335 - 375	Samudra Gupta.
	c. 375 - 415	Candra Gupta II.
	c. 415 - 454	Kumāra Gupta I.
	c. 454	First Huna Invasion.

c. 455 - 467	Skanda Gupta.
c. 495	Second Huna Invasion.
c. 540	End of Imperial Gupta Dynasty.
c. 606 - 647	Harṣa king of Kāṇyakubja.

Northern India (Dynasties)

A.D.	712	Arabs occupy Sind.
	c. 730	Yaśovarman of Kāṇyakubja.
	c. 760 - 1142	Pālas of Bengal and Bihar.
	c. 800 - 1019	Pratihārās of Kanyakubja.
	c. 916 - 1203	Caṇdellās of Bundelkhand.
	c. 950 - 1195	Kalacūris of Tripuri (Madhya Pradesh).
	c. 973 - 1192	Cahamānas of Ajmer.
	c. 974 - 1238	Cālukyas of Gujarat.
	c. 974 - 1060	Paramaras of Dhārā (Malwa).
	c. 1118- 1199	Senas of Bengal.
	1192-	Second Battle of Tarain.

Southern Peninsula (Dynasties)

A.D	c. 300 - 888	Pallavas of Kāñcī (Madras State).
	c. 550 - 757	First Cālukya Dynasty, of Vatapi (Western and Central Deccan).
	c. 757 - 973	Rāṣṭrakuṭas of Manyakheṭa (Western and Central Deccan).
	c. 850 - 1276	Colas of Tanjore (Madras State).
	973 - c. 1189	Second Calukya Dynasty, of Kalyani (Western and Central Deccan).
	c. 1110 - 1327	Hoysālās of Dwarasamudra (Central and Southern Deccan).
	c. 1190 -1294	Yādavas of Devagiri (Northern Deccan).
	c. 1197 - 1323	Kākaṭiyas of Warangal (Eastern Deccan).
	c. 1216 - 1327	Pāṇḍyas of Madurai (Madras State).
	c. 1336 - 1565	Vijayanagara Empire.

TRANSLITERATION

VOWELS

Short:	अ	इ	उ	ऋ	लृ		
	a	i	u	ṛ	ḷ		
Long :	आ	ई	ऊ	ए	ओ	ऐ	औ
	ā	ī	ū	e	o	ai	au

Anusvāra : ˙ = ṃ

Visarga : : = ḥ

Non-aspirant : ऽ = '

CONSONANTS

Classified :	क्	ख्	ग्	घ्	ङ्			
	k	kh	g	gh	ṅ			
	च्	छ्	ज्	झ्	ञ्			
	c	ch	j	jh	ñ			
	ट्	ठ्	ड्	ढ्	ण्			
	ṭ	ṭh	ḍ	ḍh	ṇ			
	त्	थ्	द्	ध्	न्			
	t	th	d	dh	n			
	प्	फ्	ब्	भ्	म्			
	p	ph	b	bh	m			
Unclassified :	य्	र्	ल्	व्	श्	ष्	स्	ह्
	Y	r	l	v	ś	ṣ	s	h
Compound :	क्ष्	त्र्	ज्ञ्					
	kṣ	tr	jñ					

Stone Age Techniques

VIDULA JAYASWAL

The basic objective in Stone Age was to obtain desired shapes by breaking rock pieces. The artificial chipping of stones is termed in prehistory as *'Flaking'*. In all the three stages of Stone Age, e.g., the Palaeolithic, the Mesolithic and the Neolithic, various ways or methods of flaking were initiated and practised. It was only in the Neolithic period, modification of tool-surfaces was also done by grinding. It may, therefore be held that, the history of lithic technology is more or less an account of flaking techniques. Methods of tool making during Stone Age are marked by two noteworthy trends viz., process of evolution or development of techniques from crude to refine, and universality in the succession of technological stages through out the world. The first pattern has been discussed in this paper a little later. The second trend does not bear direct relevance to the present theme. But, it may be mentioned that the element of universality has been explained by the anthropologists in terms of the 'psychic unity of man kind' (Herskovits, 1955, p. 111). Inspite of this general pattern of development each of the region has its own set of evidence which has contributed, in one way or the other. It is more in case of the history of techniques of the Stone Age, as the remains of the prehistoric period are of very fragmentary nature.

Data obtained from various regions, thus, needs to be woven together in such a way that the acquired set of evidence is critically viewed against the known history, and also adds towards enriching the knowledge further.

Our understanding of Stone Age technology depends on the collective efforts of the international galaxy of scholars. The experiments conducted by French prehistorians such as Bordes (1947; 1961), Tixier (1963), the British prehistorian Leakey, L.S.B. (1967), and the American prehistorian Crabtree, D. (Bordes & Crabtree, 1969), are glaring examples. Not only have they explained various methods of tool making, but they have also provided objective terminologies and ways for the study of the lithic collections (Leakey, 1967; Bordes, 1961; Movius, 1948; Tixier, 1963). Utilization of the important methodologies and the related terms is imperative for the study of prehistoric evidence for any region. Unfortunately, due to historical reasons, there have been shifts and changes of

terminologies in the studies of Stone Age in India. The terms denoting periodization, as well as, techniques were effected by this. For example, Palaeolithic- Mesolithic set of terms was replaced by the Stone Age set, e.g., Early Stone Age for Lower Palaeolithic, Middle Stone Age for Middle Palaeolithic and Late Stone Age for Mesolithic.

But about a decade later the Palaeolithic-Mesolithic set was again found useful (Misra, 1962 pp. 113-124; Jayaswal, 1978, pp. 10-11; Agrawal, & Ghosh, 1972, pp. 504-509).

Similarly, 'Prepared Core', 'Faceted Core', 'Faceted Striking Platform' etc., were the names which replaced the term *Levallois technique* in Africa (*PROPA* , 1952, p. 9). This was followed in India. Such changes have apparently added much confusion to the study of prehistoric remains. The author supports Bordes' plea (Bordes 1961, p.13) and holds that the terms related to technique denote a specific process or method of working only. These do not suggest any cultural implications even if the name has been coined after a site of some far distant foreign land (Jayaswal, 1978, pp. 19-22). It may be mentioned that this author prefers to use all such nomenclatures which have wide acceptance in the literature on World Prehistory. This includes all terms denoting periodization, techno-culture stages, tool-types and techniques.

On the basis of these reasons, the proposed study of Stone Age technologies in India has been viewed against the background of the evidence retrieved from all the important regions of the world. The account of the technologies has been divided initially within three parts - the Palaeolithic, the Mesolithic and the Neolithic. The technological features of India in each of the section has been discussed after a resume of important techniques which were prevalent during each of the three stages. It may also be put to record that the observations made on technological characteristics of the Palaeolithic remains in India are based on the author's own studies. While working on the Palaeolithic techniques and problem of Pebble-tools, all the important prehistoric collections of the country were examined by Jayaswal (1978; 1982). Besides, relevant published reports were also found useful, particularly in view of chronological observations.

I. Techniques of the Palaeolithic Period

Numerous techniques which were prevalent during Palaeolithic Period, on the basis of the aims of their utility can be grouped within three categories.

A. Techniques used for shaping tools

B. Techniques for detaching flakes and blades

C. Techniques for modifying edge or tip of tools

A. Techniques used for shaping Tools

Tool making in human history was initiated at about 1.8 to 2 million years ago. The Pleistocene sequence and the absolute dates, which are obtained from the Olduvai Gorge and other sites of East Africa, provide evidence for this incident (Leakey L.S.B., 1965; Clark, 1982, pp. 30-34). The earliest form which man made

was, one edged crude chopping or cutting implement (Leakey L.S.B., 1951). The only effort made in this case was to acquire an edge on small to medium sized pebble or cobble. Flaking of one surface (unifacial) at an end of the select piece of rock, or from both the surfaces (bifacial) of the same edge (*Fig.1*), could provide the desired form of working implement.

On account of the nature of flaking this group of tools are broadly divided into Chopper (the one with unifacially flaked edge), and Chopping tool (the bifacially flaked specimen).

These terminologies received wide acceptance after being introduced by Movius (Movius, 1948, pp. 329-420). As their techno-typological categories are made mostly on pebbles, the other frequently used nomenclature for this group is Pebble tools (Bordes, 1968; Jayaswal, 1982).

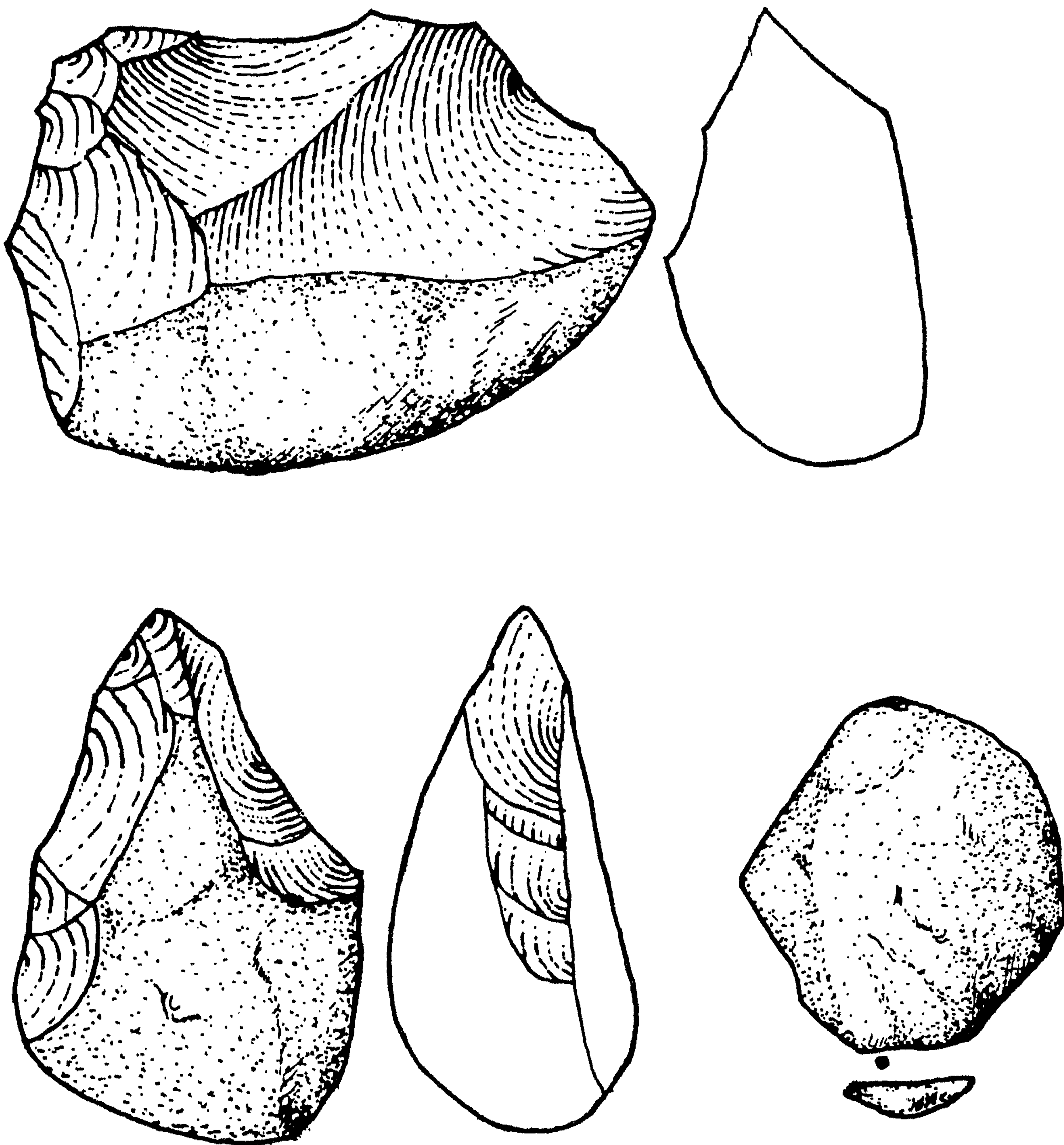


Fig.1. Chopper, Chopping tool & By-product flake

Besides East Africa where Pebble tools or 'Oldowan culture (a term used after the type site Olduvai Gorge) remains' occur in the earliest context (Leakey, L.S.B., 1951), the spread of this tool tradition in a little later context is also reported from North and South Africa, western Europe, Central, South and South- east Asia (Bordes, 1968, pp. 83-97). Pebble tools in India have concentration in the north and north-west, which appears to form part of the south-east Asian spread of this tradition (Jayaswal, 1982, p.2). Besides, there are also a few small pockets in peninsular India where chopper and chopping tool tradition existed in culture isolation (Jayaswal, 1982, pp. 57-83).

Chopper and chopping tools of the earliest facies were made by direct percussion stone hammer technique. In the later period the same morphology of these tools were attained also by the use of the direct percussion cylinder hammer or soft hammer technique.

A.1 Direct Percussion Stone Hammer Technique

In this method the selected piece of stone which is to be converted into a tool, is held in one hand (generally in left hand). A medium sized, round stone hammer is held in the other hand (the right). Hard blows are delivered on the tool's surface by hitting the hammer (*Fig.2*).

Due to the use of heavy and hard hammer and the delivery of strong blows, the flakes which are detached from the surface of the tool under making are generally

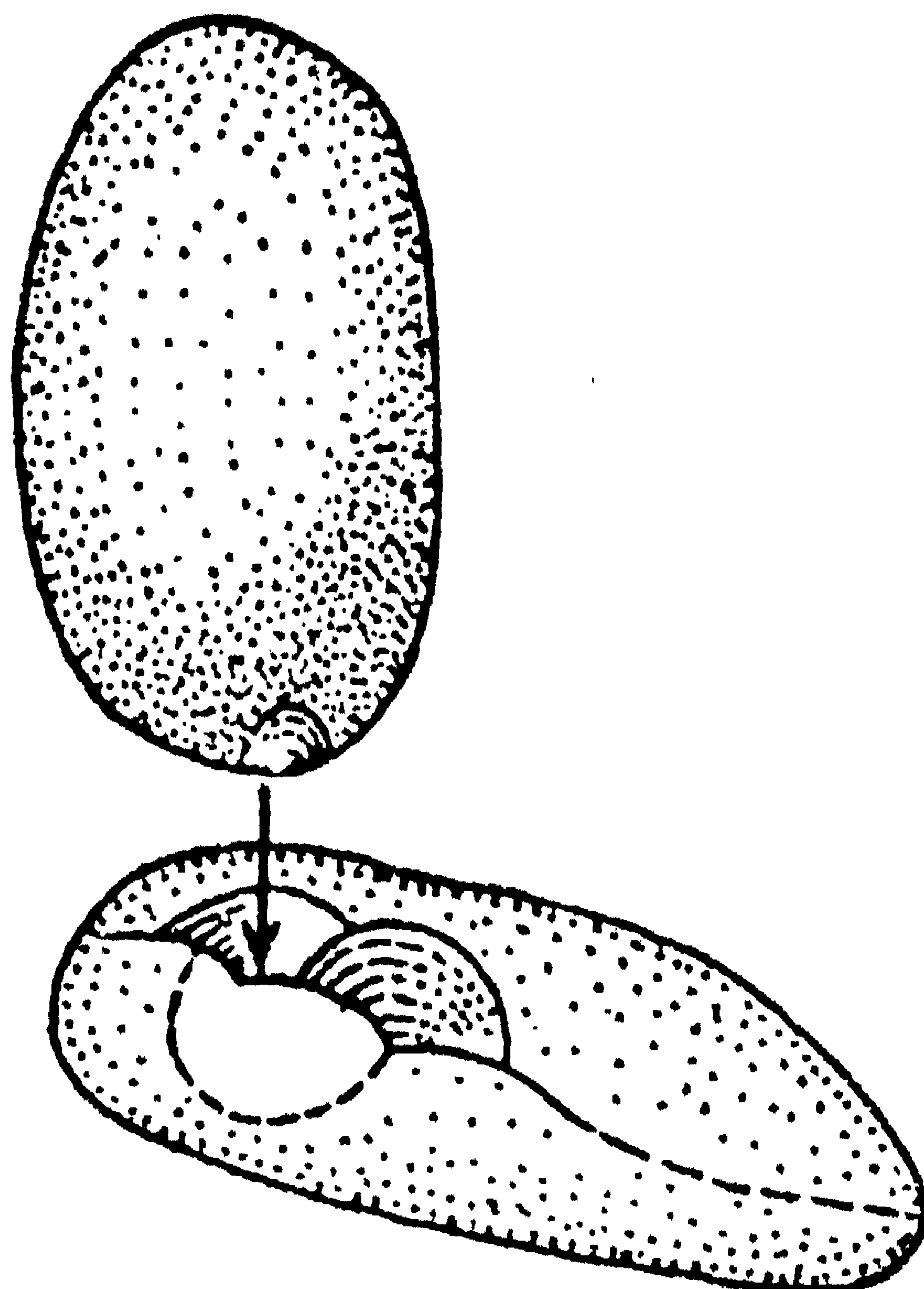


Fig.2. Direct Percussion Stone Hammer Technique

thick and of medium size. The resultant scars appearing on the tool surface are deep and rudimentary, and provide crude look to the worked specimen.

In correspondence with this, the by-product flakes, which come out during the process of flaking the part of the tool, in case of the direct percussion stone hammer technique, retain mostly natural stone or cortexed surface on the upper part (dorsal) and also have similar unprepared striking platform (*Fig.1*). Besides these completely unprepared flakes, in the flaking debris of Pebble tools some partly or fully flaked dorsal surfaced and striking platformed flakes could also be found. Such by-product flakes are usually the result of reflaking of the same edge or surface in more than one series, or flaking at very close intervals as to cover the part of the earlier flaked surface (*Fig.3*). The direct percussion stone hammer technique in India was widely practiced during the Lower Palaeolithic period. The Pebble tool complex of the north and the north-western part of this sub-continent was made primarily by this technique (Jayaswal, 1982, p. 45). Not only chopper and chopping tools of such sites as Guler (Lal, 1956), Bilaspur (*IAR* : 1962-63, pp.37- 38) in Beas and Banganga valleys and Lahchura in Uttar Pradesh (Pant, 1982, pp. 39-44) are characterized by deep, crude flaking, but also many of the flakes which are found in association with these tools have cortexed dorsal and unprepared striking platforms (Jayaswal, 1978, pp. 89-95, Jayaswal, 1982, pp. 45-63). But it may be noted that use of this technique in India appears to be much later in date than the African evidence.

For the deposits in the Potwar region which retains the remains of this technique are datable to the Middle Pleistocene period (De Terra & Paterson, 1949, p. 295),

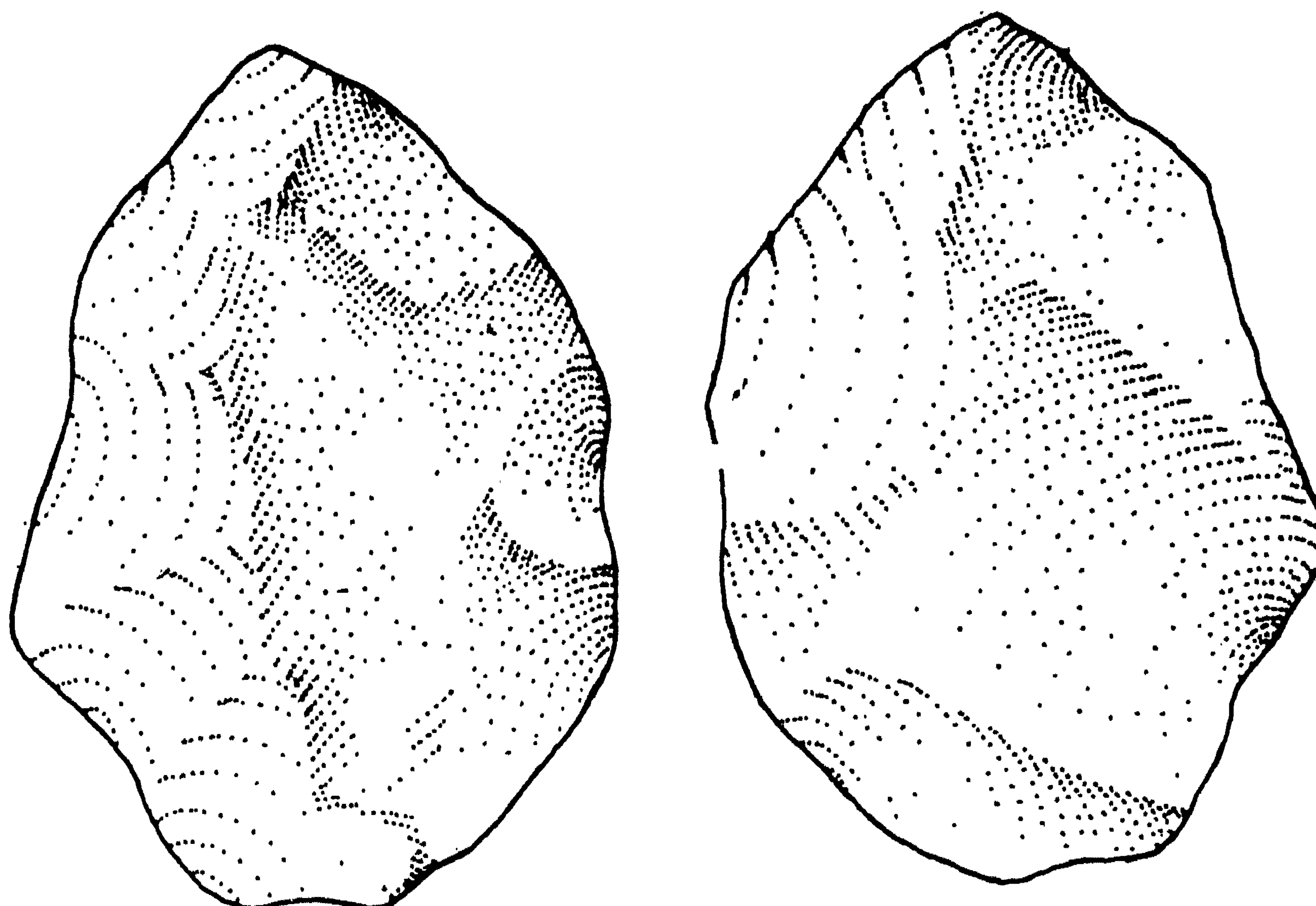


Fig.3. Abbevillian Handaxe

while African evidence suggest an Early Pleistocene date (1.8 million is the date accepted for the beginning of the Pleistocene) (Clark, 1982, p. 36).

Pebble tool tradition in India is named as the 'Soanian/Sohanian culture' after the concentration of their find spots in the valley of Soan or Sohan of Pakistan (De Terra & Paterson, 1939, p. 2).

It may be put to record that though initiated at a very early date, the direct percussion stone hammer technique continued to be used all over the world in all the succeeding periods. But, later on when this very technique was utilized for making another form, the handaxe, this method was given a different name i.e. 'Abbevillian'. According to the evidence obtained from Africa, the basic form of handaxe had evolved from chopper and chopping tools (Bordes, 1968, p. 51). It is therefore, logical to presume that the same technique which was used for the making of the chopper and chopping tools were being practiced for making of the earlier forms of handaxes.

A.2 Abbevillian Technique

This technique has derived its name from the site L Abbeville in France, where it was recognized for the first time (Bordes, 1968, pp. 52-54). This infact has the same types of flaking scars which are found to be on the Pebble tools made by the direct percussion stone hammer technique. Some time back there was a belief that use of this term would suggest culture contact of Africa or Asia with Europe, where Abbevillian was also recognized as an early stage of handaxe based culture. But this term is now used both for technique and culture stage quite independent from each other. In Europe Abbevillian stage is characterized by crude handaxes having deep flake-scars. The rough pointed tip, unflaked butt and zig-zagged sides suggest that these stone hammered specimens were proto-types of later finely made handaxes of the Acheulian tradition (*Fig.3*).

Not a single collection of the Indian sub-continent has been identified as Abbevillian. But some times the glimpses of this technique can be found in a number of techno-typologically advance industries..Occurence of crude handaxes, for instance, showing stone hammered scars in Acheulian collection evidence practice of the technique under consideration. There is a possibility that such specimens were the ones in which later stage of fine finishing could not be complied. However, there are a few sites such as Mahadeo-piparia (Supekar, 1968), Bariarpur (Joshi, 1961) etc., where along with Pebble tools, handaxes made by stone hammers are reported (Jayaswal, 1982, pp. 71-74). Fine Acheulian working in these are restricted.

A.3 Direct Percussion - Soft/Cylindrical Hammer Technique

The continuation of the direct percussion technique was modified in later times by the use of hammers of elongated shape and of softer material such as bone, antler and wood etc. (Bordes, 1968, p. 24). The advantage of the use of such hammer was that the delivered blow could take out only small and shallow flakes (*Fig.4*).

This helped in controlling the chipping process. It was thus possible to make fine tips and well formed shapes of specialized implements like handaxe and cleaver (*Fig.5*).

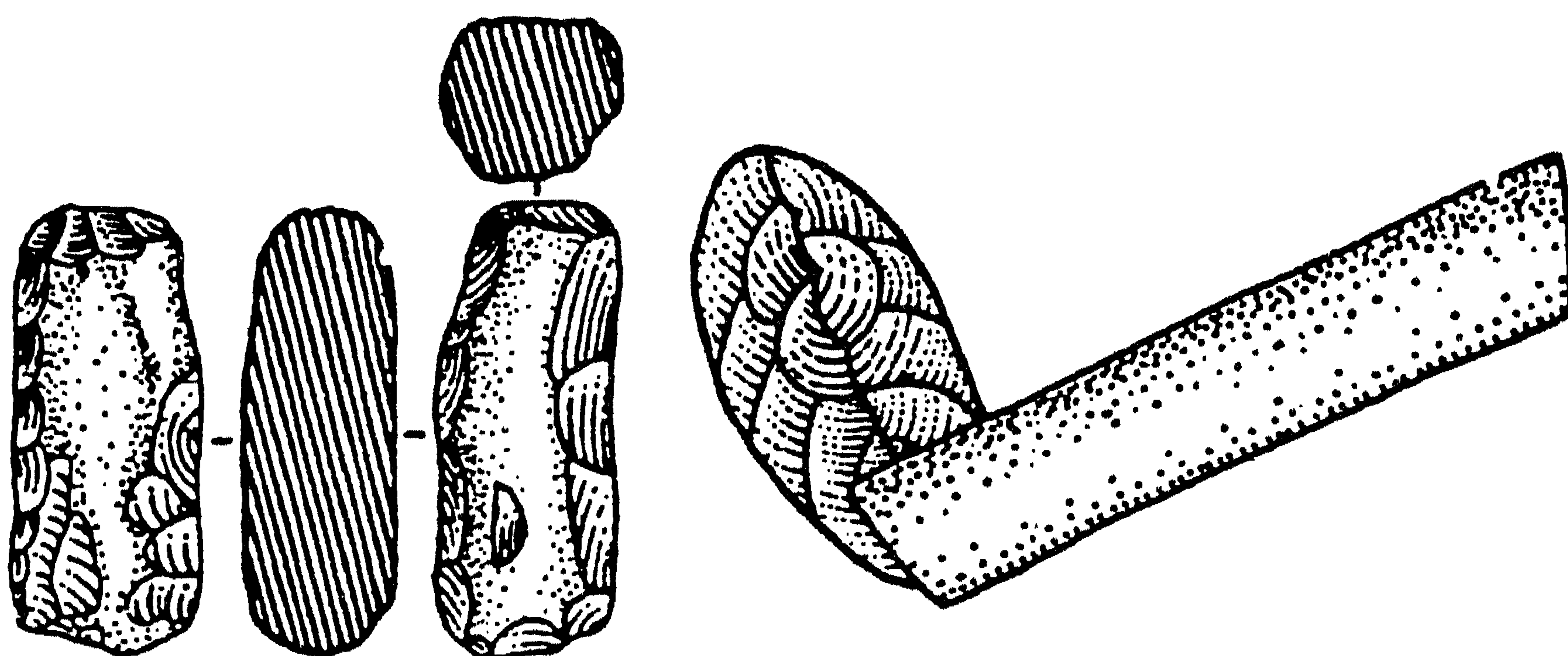


Fig.4. Cylinder Hammer/Acheulian Technique

Some times edge of chopper and chopping tools were also made by this technique. The reminiscents of this technique in the form of small and shallow flake scars, were recognized at Sant Acheul site of France, after which the technique is also known as *Acheulian technique* (Bordes, 1968, pp. 51-52).

In Africa, some time back this technique was named as 'Chellean'. The handaxes made in Acheulian technique are the characteristic form of the Acheulian culture, which appears to have originated in Africa around 1.5 million years ago (Clark, 1982, p. 41). but, its complete successive stages are well documented in western Europe. The Lower, Middle and Upper or Advanced Acheulian stages besides typological modification also evidence development of Acheulian technique. It was the Advanced Acheulian stage which was particularly widespread in European, African and perhaps parts of Asian continents.

Numerous sites which are reported from peninsular India are characterised by Advanced or Late Acheulian features. The typo- technological characters of our industries compare well with the Isimila, Olorgesaile and Kalambo fall industries of Africa. These Acheulian collections were studies with a view to comparing the India data, by this author at University of California, Berkeley (USA). It was noted that besides finely made lanceolate and ovate forms of handaxes, the flake cleavers of Indian Acheulian tool- kit also have much technological similarities with the African industries of the later facies of Acheulian.

In the absence of the absolute dates, and due to the typo- technological similarities with Advanced Acheulian of Africa, Indian Acheulian appears to be datable between one million and 0.5/0.4 million years. The Acheulian remains of the Indian sub- continent was named as 'Madrasian Culture', after the discovery of first cleaver, and also after the concentration of sites yielding handaxes and cleavers near Madras in the later investigations (Krishnaswami, 1948). But, the Acheulian term has also attained wide acceptance in India. Some of very finely worked handaxes of refine Acheulian technique have been reported from Attirampakkam (Krishnaswami, 1938; *Indian Archaeology 1964-65: A Review*, 20), Vadamadurai(*Indian Archaeology 1966-67: A Review*,20-21; Jayaswal, 1985),

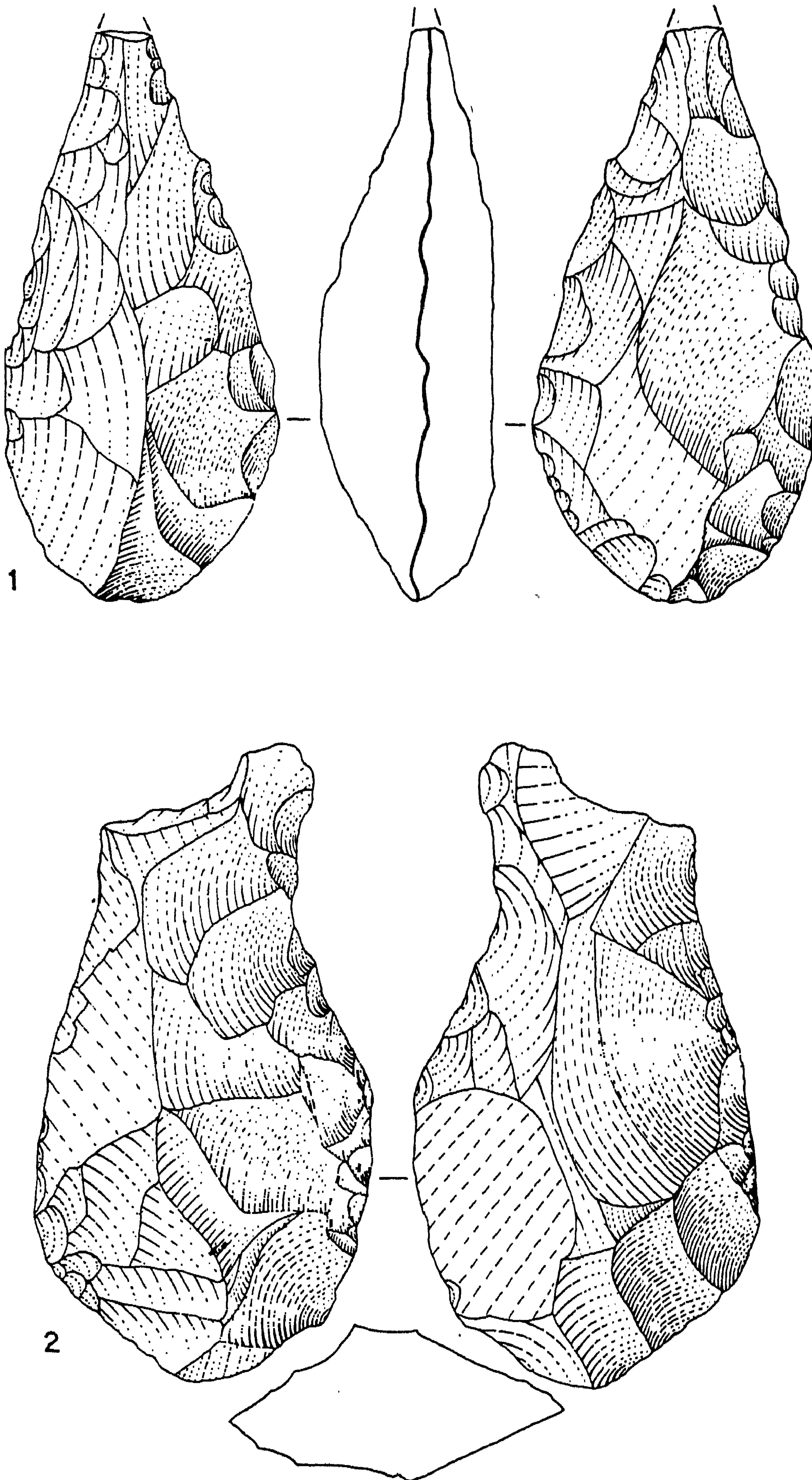


Fig.5. Handaxe & Cleaver of Acheulian tradition

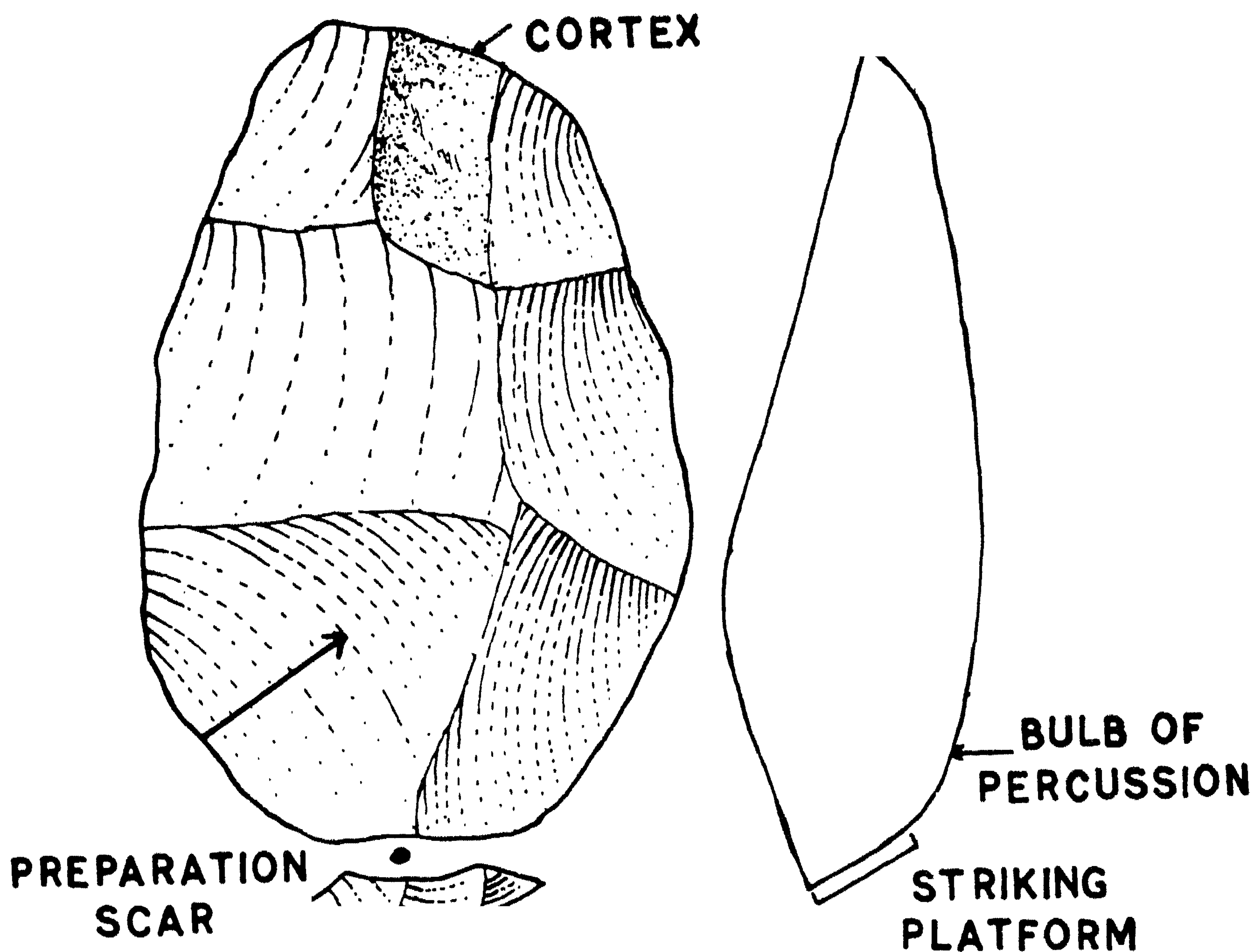


Fig.6. Flake

Gudiyam (*Indian Archaeology 1963- 64:A Review*,19) in Tamilnadu, Bhimbetka (Misra,V.N.,1985) and Adamgarh in Madhya Pradesh (Joshi, 1978), and Paisra in Bihar (Pant & Jayaswal, 1991) etc.

B. Techniques for obtaining flakes & blades

All the lithic implements discussed above belong to the category of core tools, as these were chipped from a lump of rock or stone. There are, however, majority of tools, in all the three phases of the Palaeolithic period,which are made on flakes (*Fig.6*). A specialized form of flake e.g. long (length more than double or more the breadth), parallel sided and thin is referred to as blade, which evidence culmination of flake detaching technique. For, the attainments of this technique were the input of minimum labour, wastage of very little raw material, but output of large working edges.

It may not be just a coincidence that the blade technology was perfected by the *Homo Sapiens* the proto-type of the modern man. Implements made on flakes though were common during many of the Lower Palaeolithic industries, it was the Middle Palaeolithic period in which flake element predominated and the technology of obtaining various forms of flakes were perfected. It is interesting to note that the prehistoric man, contemporary to this period, the *Neanderthal* man, had cranial capacity at times more than even some of the present day men.

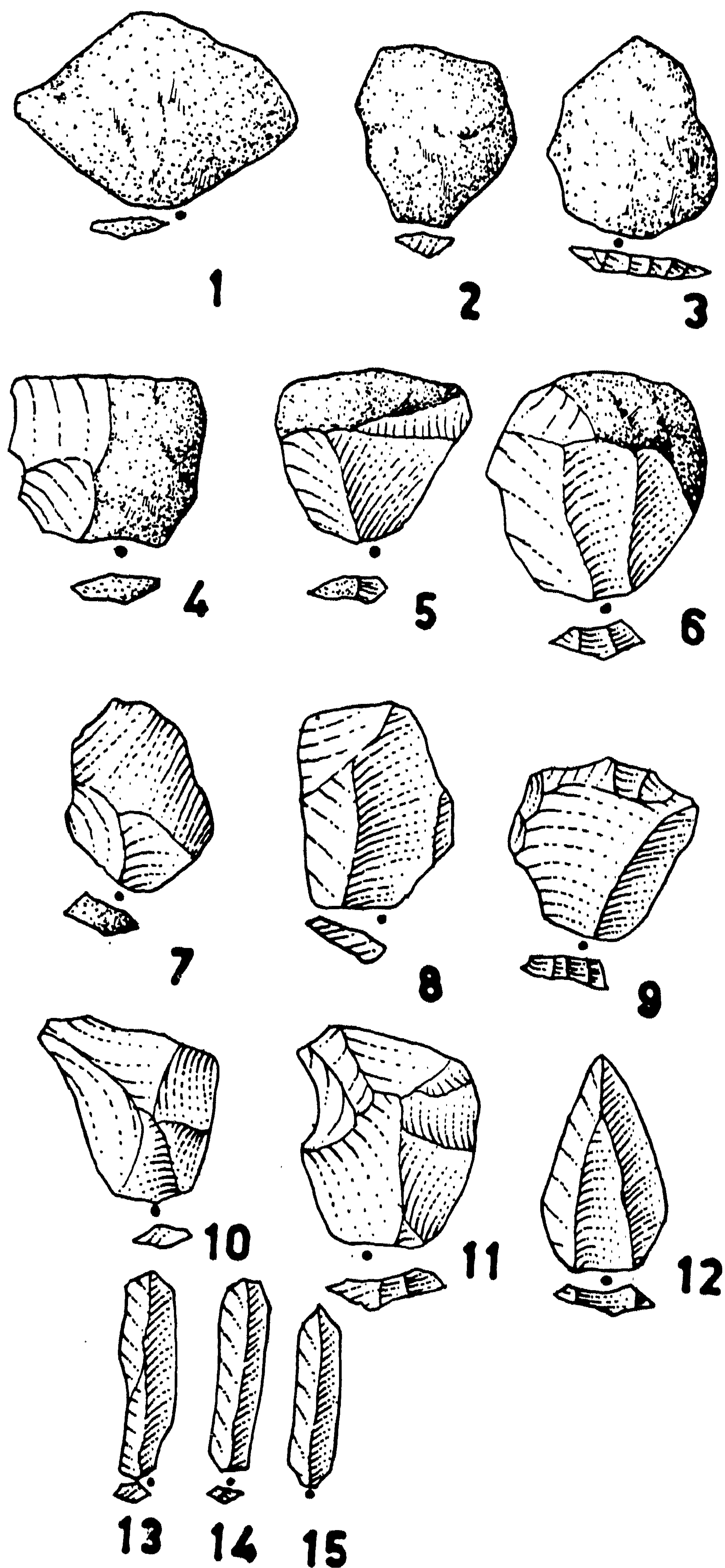


Fig.7. Flake & Blade Types

The basic factor which controls the size and shape of flake is known as mass manipulation or the manner in which the delivered force on a core travels. It has been explained by the prehistorians that the force which is applied on the surface of a stone, traverses through the weaker zones and avoids the regions with accumulated mass. In other words the depressions on the core forms the weaker areas through which force spreads easily and is effective, while the raised or thicker parts of the lump are the obstructions which is avoided by the force. In this mechanism by chipping the surface of lump of stone various kinds of weaker- zones and masses could be artificially created on the core, which could predetermine the form and size of the flake. Prehistoric man had understood this by experience, and could utilize this process to his advantage. Experiments conducted by prehistorians (Bordes, 1961; Bordes & Crabtree, 1969) has helped in replicating and, thus, understanding various flake/blade detaching mechanism of the prehistoric times.

Flakes (*Fig.6*) which are important clues for the Palaeolithic technology can be classified in many ways. For instance, on account of the objective of their detachment these form two broad groups viz., the by-products and the intentionally detached flakes meant for making implements. The by-products or the dressing flakes may be the result of the tool working or core dressing process and are the flaking *debris.*

But, the flakes which were obtained for making tools were also acquired by various methods, such as the Clactonian, the Levallois and the Mousterian etc., which we shall discuss later. But, separation of flakes into a few broad groups and their sub- groups is not easy and beyond debate. Due to this reason, the present author adopted a descriptive criterion for classification of flakes denoting various flaking techniques of the Palaeolithic period of India (Jayaswal, 1978, pp. 15-17). The classification was based on the nature of the dorsal surface and the striking platform. These categories were fifteen (*Fig.7*). Though descriptive terminologies were used for these categories, a few well defined terms as Levallois flake, Levallois point and blade etc., were retained. A brief description of the proposed classification and important features of the Palaeolithic technology which had emerged from our study has been mentioned below.

Classification of Flake/Blade Types

1. Unprepared Flake : The flakes of this group had no preparatory marks. That is to say the dorsal surface and the striking platform in this case are cortexed (pebble surface or natural nodule surface).

2. Flakes with unprepared dorsal surface but prepared and unfaceted striking platform : The dorsal surface of this flake type is similar to the above, but the striking platform, being prepared by single blow, shows an unfaceted plain surface.

3. Flake with Unprepared Dorsal Surface and Prepared & Faceted Striking Platform : Dorsal surface is similar to the types 1 & 2, but the striking platform of the flakes of this group have prepared striking platform having more than one negative scar ridges or facetes.

4. Flake with Partially Flaked Dorsal Surface and Unprepared Striking Platform : The specimens with partially flaked dorsal surface have only one or two

and rarely three half negatives or preparatory scars and nearly half of the surface of the dorsal and entire striking platform retaining unworked surface.

5. Flake with Partially Flaked Dorsal Surface and Prepared, Unfaceted Striking Platform.

6. Flake with partially flaked dorsal surface and prepared, faceted striking platform.

7. Flake with Prepared Dorsal Surface and Unprepared Striking- platform: The flake of this group, though having prepared or flaked dorsal surface, do not exhibit any definite pattern of preparation and thus could be classified as Levallois flake.

8. Flake with Prepared or Flaked Dorsal Surface and Prepared, Unfaceted Striking Platform.

9. Flake with Prepared or Flaked Dorsal Surface and prepared, faceted striking platform.

10. Levallois Flake with Unfaceted Striking Platform : The dorsal surface of this type of flake has quite a few centrally directed half negative scars, forming a hump in the centre of the specimen.

11. Levallois Flake with Faceted Striking Platform.

12. Levallois Point : The flake of the group are triangular shaped with a central ridge or a small point/triangular negative scar. The striking platform of these flakes are broad and faceted. These flakes are detached from specially prepared triangular shaped cores with central ridge and/or triangle-scar and ridge, and broad faceted striking platform at the wider end (Bordes, 1961, p.1).

13. Blade with Unfaceted Striking Platform.

14. Blade with faceted Striking Platform.

15. Blade with Micro Striking Platform : This group has very tiny striking platform, which is negligible in comparison to the prominent cone. The evidence of the application of pressure flaking is demonstrated in this category.

In correspondence with the above mentioned flake/blade types, nine major types of cores were recognized in the Palaeolithic collections of India (Jayaswal, 1978, p. 18).

1. Unprepared Core.

2. Core with Unprepared Dorsal Surface and Prepared Striking Platform.

3. Core with Partially Prepared Dorsal Surface and Unprepared Striking Platform.

4. Core with Partially Prepared Dorsal and Prepared Striking Platform.

5. Core with Prepared Dorsal Surface and Unprepared Striking Platform.

6. Core with Prepared Dorsal Surface and Prepared Striking Platform.

7. Levallois Core : The core of this group are also named 'Tortoise core'. The centrally directed preparation scars form a hump in the centre which resembles the shape of the turtle back. The striking platform is generally prepared at one of the part of the periphery of the core at nearly 90 angle to the dorsal face (*Fig.8*).

8. Bifacial Discoidal Core : It is a bifacially prepared roughly circular or oval core with bi-convex cross-section. The flake- scars on the two surfaces denote that the usually elongated centripetal flakes have been removed from them, alternately, after the usual Levallois type of preparation (*Fig.9*). The flaking agree perfectly with that of the discoidal Mousterian cores, but at the same time it differs from them at least on one point. The specimens of the Indian Palaeolithic industries have been

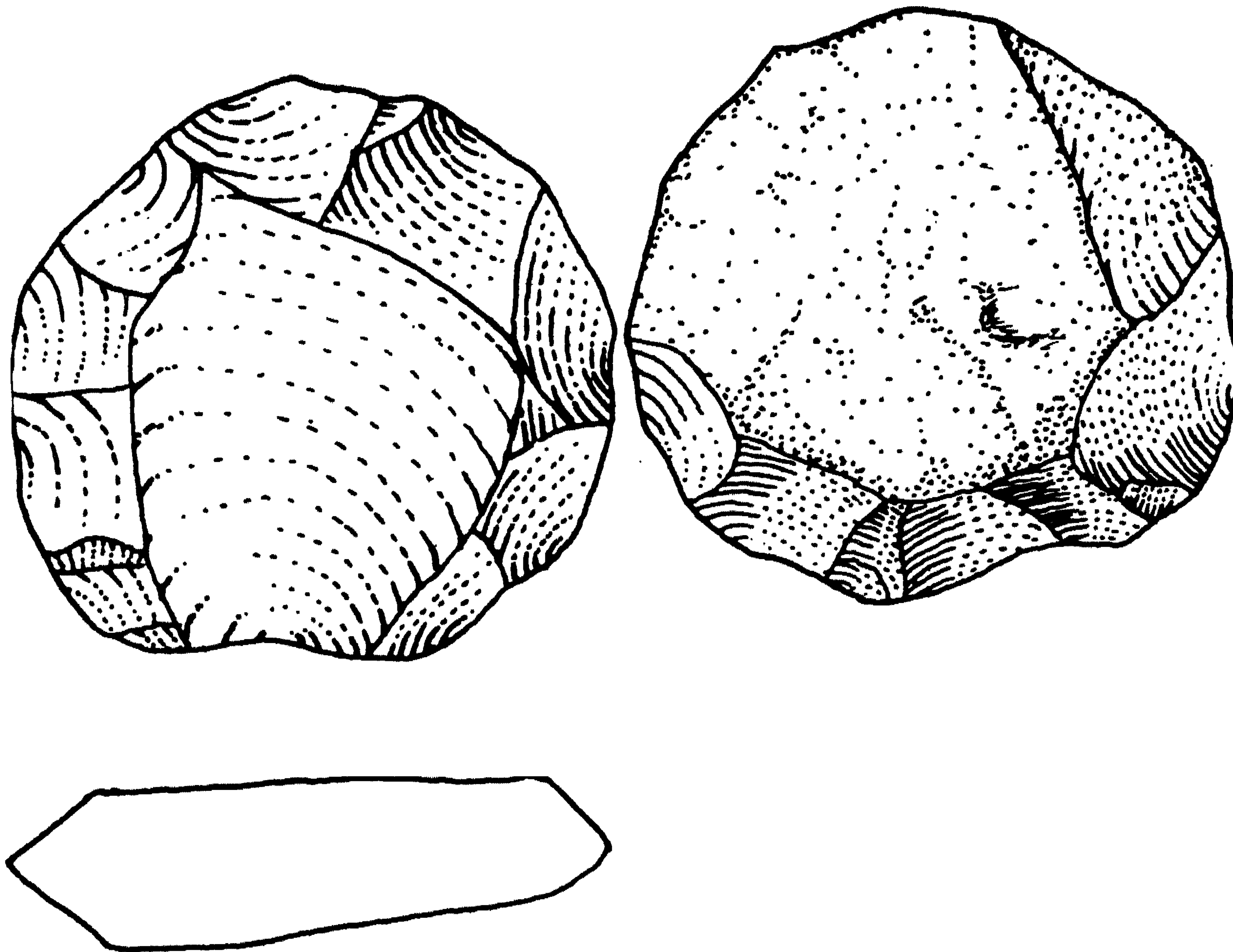


Fig.8. Levallois Core

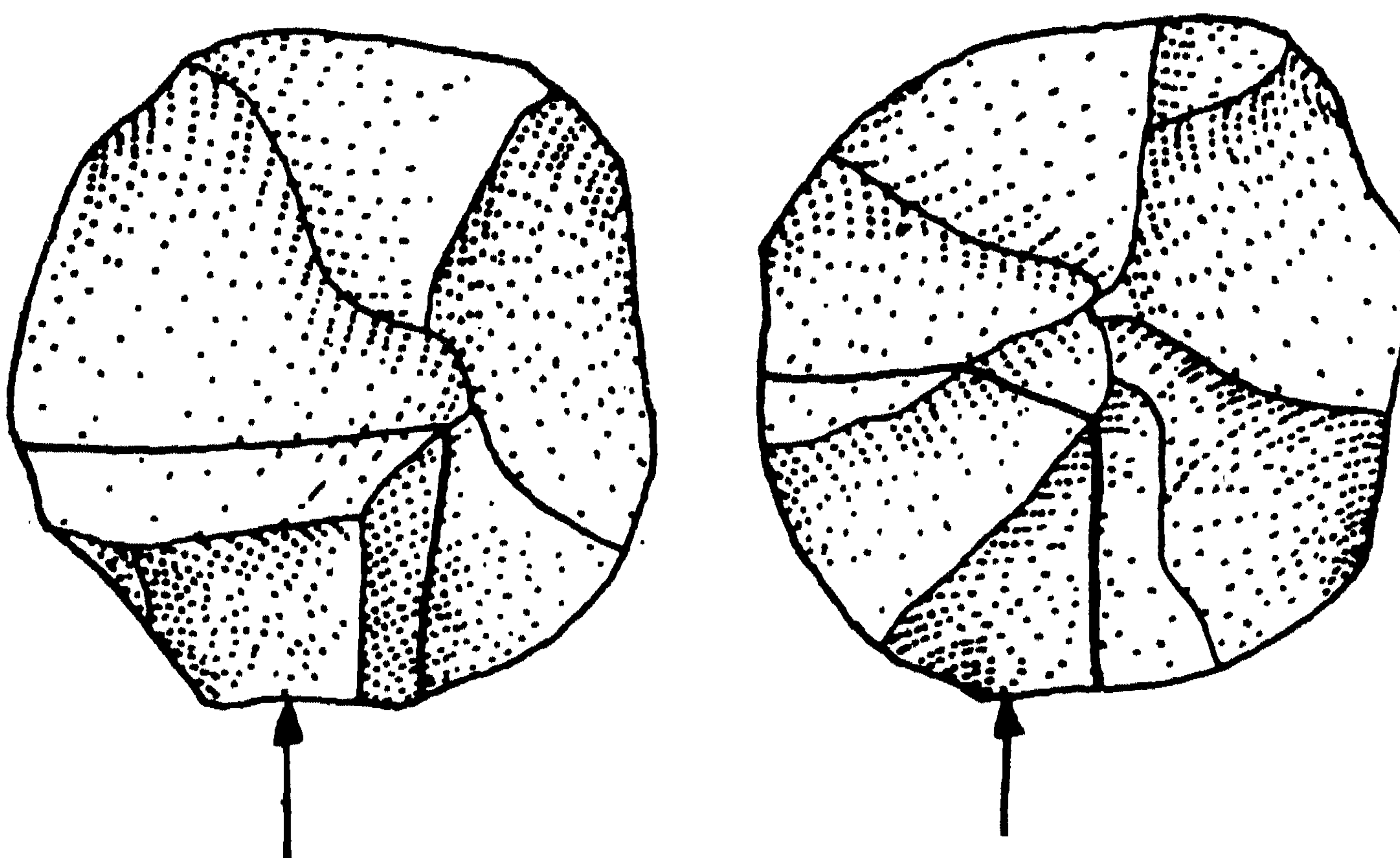


Fig.9. Mousterian Core

flaked bi-facially, while in the case of the European cores it is limited to the dorsal surface only (Bordes,1961, pp.72-73).

9. Blade Core : Cores for detaching blades are generally elongated specimens with ridge or ridges running throughout the length or a major part of the length. These may have one or two striking platform located on the end/ends, at a low angle to the dorsal face.

The unprepared flakes and cores have been found in varying proportions in all the three Palaeolithic phases of the Indian sub-continent. As many as four types within this group has been noticed (Jayaswal,1978, pp.20-21). These are :-

(1) Massive flakes,

(2) Massive cleaver-shaped flakes,

(3) Small flakes, and

(4) By-products.

(1) Massive Flakes - Unprepared : This group is also known as Clactonian flakes or flakes detached by Block-on-block technique (Bordes, 1961, p. 13). Named after the type site of Clacton-on- Sea in England, the Clactonian technique is said to be characterized by the use of block-on-block method. Big blocks of stones are hit against the stationary block or anvil to acquire flakes. The resultant flakes are massive having wide angle (about 120) between the striking platform and the ventral surface. Due to the heavy blow and hard hit these flakes retain prominent cone of percussion. In India such flakes have been found associating the Pebble tool industries of the Potwar region (De Terra & Paterson, 1939), and the Lower Palaeolithic industry of the Narmada basin (Khatri A.P. 1963, p. 186). In the tradition of typical Clactonian flakes they are characterized by unprepared dorsal surface and striking platform and high angle between the striking platform and the ventral surface. These are also massive sized specimens.

(2) Massive Cleaver-shaped Flakes - Unprepared flakes: Though similar in technique and size to the preceding one, this group is characterized by cleaver-shaped flakes. Unique to the Nagarjunakonda valley, the flakes of this category have unprepared dorsal surface and striking platform, but are cleaver shaped (Jayaswal, 1978, p. 20). Technologically they exhibit a very striking feature. Only those boulders which showed projecting natural curvatures of cleaver shape were selected for detaching these flakes (*Fig.10*). Thereafter, a single heavy blow at the centre of the curvature was sufficient to produce a broad flake having a cleaver-edge on one side.

It may, thus, be said that without preparation, the shape of the flake was determined before its separation from the core. These flakes also seem to be detached by block-on-block technique, but one wonders whether these can be logically grouped under Clactonian flakes, as their shapes could be predetermined on the core in accordance with the available natural curvatures.

(3) Small Flakes - Unprepared : Frequently found in the Lower and Middle Palaeolithic industries, this group of flakes are smaller than the above two, but larger than the by-products. A sizable percentage of these are retouched and converted into finished tools such as side-scrapers, points etc. The technique

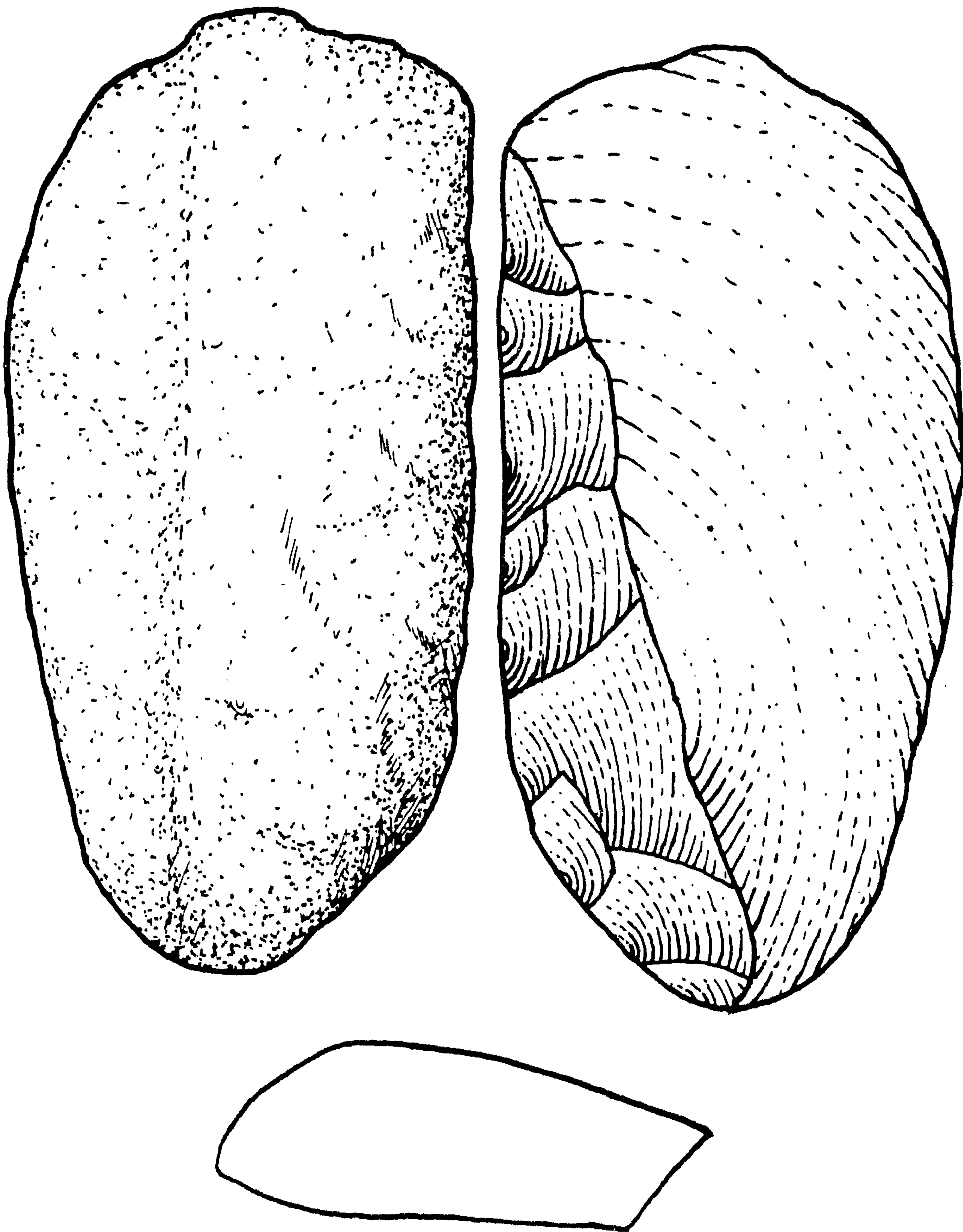


Fig.10. Cleaver from Nagarjunkonda Valley

applied for obtaining this group appears to be the direct percussion stone hammer technique.

(4) By-products : This group of flakes frequently occurs in the Pebble tool industries. The stone hammer direct percussion technique, whenever applied for manufacturing crude implements like chopper and chopping tools, produces a number of these flakes. But, the separation of by-products from the small intentionally detached flakes of the third group, needs caution. Though it may not always be possible to group them with confidence,this author has suggested a

tentative method (Jayaswal 1978, pp. 7, 17). It was observed that the by-products are usually much smaller than those flakes of an industry which have either been converted into finished tools or were seemingly meant to be so. These are comparatively smaller than the biggest scar appearing on the artifact of an industry. Often they are not retouched and do not carry definite marks of preparation. It may be mentioned that some of the flakes with partially flaked dorsal surface and flaked but unfaceted striking platforms also belong to the by-product categories.

It may be mentioned that in the proposed classification there are three other flake types namely, flakes with unprepared dorsal surface but prepared striking platform, partially prepared flakes, and prepared flakes which deserve a few line of explanation. If compared with some of the flakes of the typical Clactonian industries of England, several specimens of the first two types may be found strikingly similar to them. The partially prepared flakes usually bear one or two half negatives on the dorsal surface. It can hardly be proved that these half negatives are marks of core preparation. But at times it is equally difficult to disapprove it either. Many specimens which have been grouped by us as prepared flakes, similarly may be termed as Levallois, if attempts were made to find parallels in some of the European publications (Bordes F. 1961).

There are others in this very group which seem to be the result of imperfect Levallois technique and may be termed as 'Proto- Levallois' or even 'Atypical Levallois' (Bordes, 1961, p. 13).

Levallois technique : It is one of the most misunderstood techniques of the Palaeolithic period. Not only there has been debate for the use of nomenclatures, which was mentioned earlier in this paper, but even the processes involved in this technique are not always clear. F. Borde's explanations have been found to be most logical and are based on practical experience (Bordes, 1961, pp. 17-20). His definitions and technological classifications have been mostly followed here.

The broad definition of Levallois technique includes more than one method of obtaining flake and blade. The principle underlying this technique is that the form of the flake/blade is predetermined on the core before it is detached. This is achieved by the preparation of cores. Preparation of core is confined primarily to the dorsal or the surface from which the flake is to be obtained, and the striking platform on which the final blow is delivered. The dorsal surface is prepared with a view to diverting force in various ways, such as to have circular, oval, cleaver-shaped, triangular or rectangular periphery. The distribution of the applied force in these manners could yield flakes of the desired shapes. On the other hand the nature, extent and position of striking platform (the angle between the dorsal and the platform) also needed preparation. The position and strength of blow was another important factor for the process. Due to various ways of the core preparation at least four distinct categories of flakes could be obtained by application of the Levallois technique. These are - Levallois technique for oval and circular flakes, Levallois point technique, Para-Levallois, and Levallois blade technique.

(1) *Levallois Technique for detaching Oval and Circular Flakes*: Made on medium sized oval or circular lump of stone, this technique is also known as 'Tortoise core techniques'. The dorsal surface of a typical tortoise core is prepared by centrally directed preparatory flakes, which form a hump in the centre. The

striking platform is prepared at one of the ends by removing small chips or facetes (*Fig.8*). The applied blow on the striking platform in this case result in the breakage of circular or oval flake depending on the form of the core and the placement of the hump on the core.

In our classification the oval and round shaped flakes of types 10 and 11 belong to this category. In the Paleolithic collections of India the use of Levallois technique is quite well represented. For example, in the Lower Palaeolithic industries the proportion of Levallois flakes occupies upto 15%, while in some of the Middle Palaeolithic industries they form 42% of the flake group (Jayaswal, 1978, p. 199). This feature is quite contrary to the general belief that Levallois technique is poorly represented in the Indian sub-continent.

(2) *Technique of Levallois Point* : The type 12 of our flake/blade classification includes those triangular flakes which were detached by Levallois technique. Levallois point in general are very rare in all the Indian Palaeolithic phase (Jayaswal, 1978, p. 199).

In the Lower Palaeolithic phase only though almost fifty percent of the industries had Levallois points, yet their number were found to be very limited (Jayaswal, 1978, Table - 2, pp.138-139). The percentage of Levallois points in the Lower Palaeolithic industries never exceeded 1.9%. In comparison to this, the type is well represented in the Middle Palaeolithic industries of the sub-continent (Jayaswal, 1978, Table - 6, pp 170 - 171). But only three industries viz., Vedullacervu, Tamkur and Mahadeo-piparia evidence the use of this technique.

This feature is very different from Europe, particularly the western part, where Levallois technique in general and Points in particular were predominating typical Mousterian industries.

(3) *Para-Levallois Technique* : This technique is also known in the literature on the Palaeolithic period as Victoria - west and Vaal technique, after the regions in Africa, where Acheulian cleavers made on broad flakes were found in plenty (Bordes, 1968, p. 69). The sides or the periphery of large boulder or block of stone is prepared by removing a few large flakes from top and bottom. Striking platform is prepared on a part of the top face. A heavy blow when delivered at the striking platform, results in a broad cleaver-shaped flakes with sharp and broad cutting edge (*Fig.11*). A little working on the side or sides of such a flake should make a perfect cleaver. In the Palaeolithic industries of India the presence of this technique is found in most of the advanced Achulian industries e.g., Attirampakkam, Paisra, Belan valley etc. Dominant proportion of such cleavers and cleaver- flakes were noticed by this author in the tool-kit of Lalitpur and Chirki Nevasa (Jayaswal, 1978, p. 22).

The raw material used for Lalitpur industry is granite while for Chiriki-Nevasa the dolerite was used. The big blocks of stones in both of the cases were obtained from the nearby outcrops of Bundelkhand granite and dyke of dolerite. The angular and irregular surfaces of the blocks were prepared in the manner of Para-Levallois, and cleaver-shaped flakes were detached. The flakes detached were mostly broad and were of such perfection that only a little secondary working was needed to covert them into perfect finished cleavers.

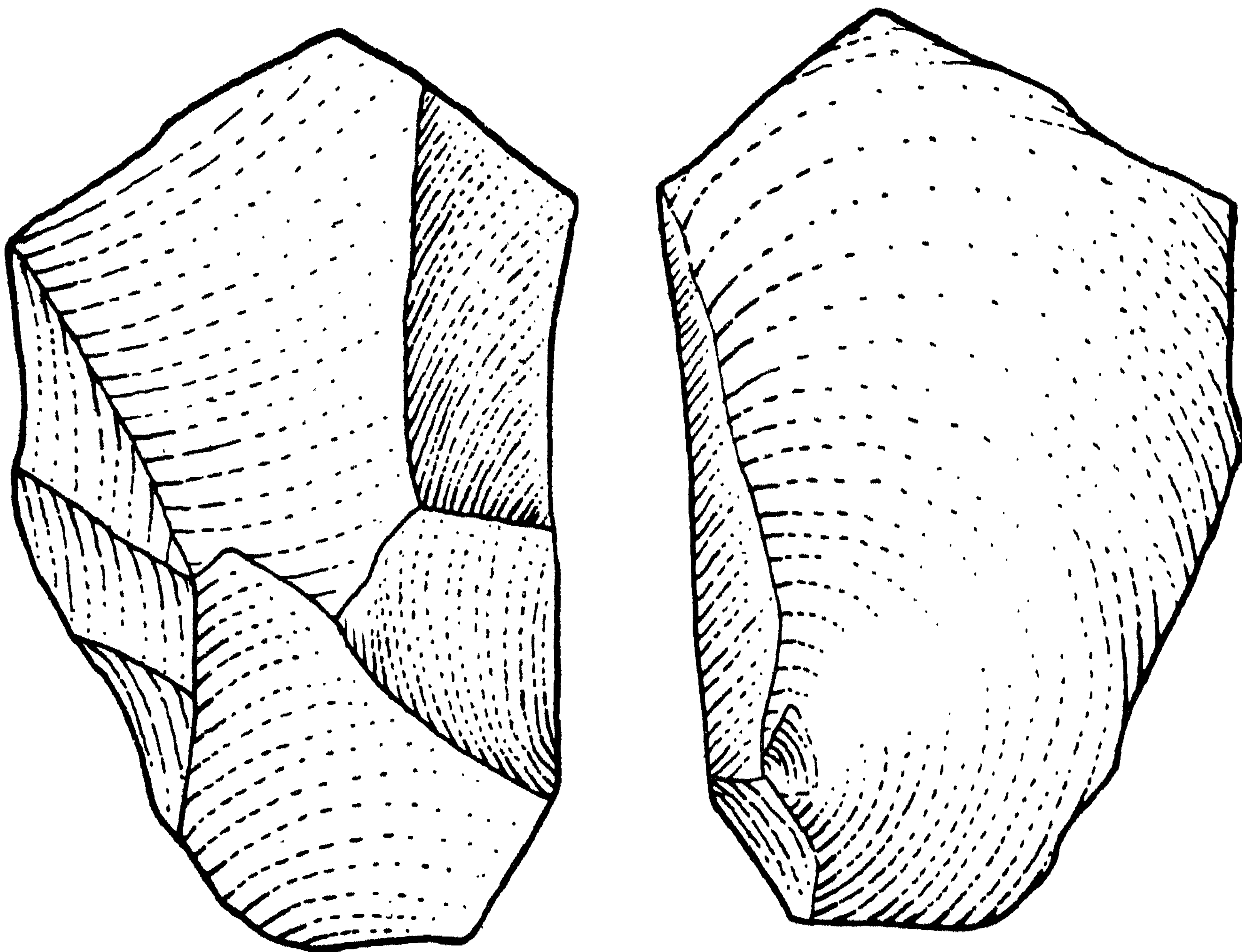


Fig.11. Para-Levallois Cleaver-flake from Paisra

(4) *Levallois Blade Technique* : Blades detached by Levallois technique evidence a transition between the flake detaching technique and the blade techniques. In fact it is imperfect or proto-technique of obtaining blade. The broad and rectangular specimens of this category many a times have lesser length in comparison to the ratio of breadth. Thus, they fall short of the definition of true blades. Presence of this technique, to the best of our knowledge is neither reported nor has this author observed in the Indian Stone Age collections. Various scholars have experimented on the different ways of obtaining blades. The result acquired helped understanding and elaborating the processes of blade detaching techniques. Experiments carried out by Bordes and Crabtree (1969), has well demonstrated the process. They write, " the first step of core preparation is to eliminate the rounded surface and establish at first striking platform for preparation of a ridge which is to guide the first blade.

Once a striking platform is established by a side blow at one end, one can immediately begin taking off blades, the first of which will have its dorsal side completely covered with cortex" (Bordes & Crabtree 1969, pp. 3-4).

In many types the striking platform is almost at a right angle to the plane of the core. Various methods like 'pressure flaking' (Sankalia, 1964,pp 34-8), and indirect percussion have been suggested for detaching a series of blades by rotating a single core. The cores could be of a various shapes i.e., rectangular, pyramidal and prismatic etc.

Blades are rare in the Lower and the Middle Palaeolithic industries of India (Jayaswal, 1978, p. 199). The maximum frequency points of the two phases are 6% and 12% respectively. But, the industries of the Upper Palaeolithic period of the Chittoor and Kurnool districts of Andhra Pradesh, Belan valley of Uttar Pradesh and Upper Son valley of Madhya Pradesh indicate that more than fifty percent of flake/blade group belonged to the category of blade. It was also observed that the blades of the Belan and the Son valleys were comparatively longer than those of the Andhra Pradesh group (Jayaswal, 1978, p. 192). But, in comparison to Europe the blade and blade tools of the Upper Palaeolithic phase of India are marked by less perfect techniques and restricted typological forms.

The detailed technological studies which were carried out by the present author some time back have brought to notice some interesting features. For instance, it was noticed that the technological attainments of the Lower and Middle Palaeolithic periods in India did not differ widely from each other.

However, there seems to be a general preference for cruder techniques in the Lower Palaeolithic industries.

The proportion of advanced techniques such as Levallois and blade detaching techniques are slightly better in the Middle Palaeolithic phase. This position is very much different than that of Europe, where the Levallois technique is one of the diagnostic traits of the Middle Palaeolithic phase.

Similarly, it was observed that, the broad and oval shaped flakes were more common in the Lower Palaeolithic phase of India, while the elongated and round flakes were somewhat more frequent in the Middle Palaeolithic. Besides, no evidence could be retrieved to suggest that particular shapes of flakes were acquired for some typical tool forms. The only exception to this observation was the cleaver-shaped flake of the Acheulian industries. Further, it was noted that the shape of the parent core, its preparation, the angle of stroke given to detach the flake and the amount of force applied for the purpose, were the major factors responsible for determining the shape of flake/blade. During the course of our analysis of the Palaeolithic technology, it was noted that raw material is the other factor which seems to have influenced the techniques and size of flakes and blades (Jayaswal, 1978, pp. 206-211). The form and nature of raw material in a particular region i.e., the size, shape and form of nodules, pebbles and block of stones along with their composition appears to be the guiding factors. For instance, if only small pebbles were available as raw material in a region, then the prehistoric man of the region was not in a position to make very big tools out of them. On the contrary, if big blocks of stones were to be selected for the purpose in another region, the first action of the prehistoric man for manufacturing implements would be to avail manageable flakes from them and then work them out into desired tools. The Lower Palaeolithic industries from the factory sites of the Belan-Seoti valley provide illustrative example of the latter instance. Though the Lower Palaeolithic industries in general are dominated by artifacts made on core, yet the Belan group of industries show the predominance of flakes and flake-tools. For, it was necessary in this region to detach flakes first, from the big quartzite blocks and then convert them into finished tools or some times into cores for detaching flakes and blades.

It was also attempted to determine the influence of the composition of raw material on technology, during our study of Palaeolithic techniques (Jayaswal, 1972-73, pp. 64-70). For this, twelve Middle Palaeolithic industries were selected and classified within three groups on the basis of the use of raw material. These were - (1) Industries made on quartzite (rough grained rock); (2) Industries made on quartzite and minerals (rough grained and fine grained siliceous stones); and, (3) Industries consisting of tools of minerals only (fine grained siliceous rocks like chert, jasper, chalcedony etc.). The industries of Vedullachervu, Nandipalle, Vadamanu and Ramgarhwa belonged to the first group, while Mahaeo-piparia, Adamgarh, Anagwadi and Kurnool show the use of both the types of stones. The last group is formed by the industries of Tamakur, Nalgonda, Luni and Kovalli.

The percentages of Levallois element (both flake and point) indicated that this technique was more frequently employed in areas where quartzite was used for manufacturing tools. Conversely, it was least in vogue in those industries which were made on fine grained stones. In case of such industries where both the kinds of stones were used, it is quartzite which seems to be more suitable for manufacturing Levallois flakes and points.

Technological variation within a typological group of industries of the Lower Palaeolithic phase also depended on the nature of raw material. The industries of Nagarjunakonda-1 and Chirki-Nevasa, for instance, belonged to one typological group viz., cleaver dominated Acheulian group. Though cleavers were found to be dominating both of these industries, great variation was noticed in the techniques of detaching cleaver-flakes. In Nagarjunakonda valley big boulders of quartzite were available to the Acheulian man. He cleverly exploited their natural curvatures for obtaining cleaver-shaped flakes without artificially preparing the surface of the cores *(Fig.10)*. In contrast to this at Chirki-Nevasa, the raw material was obtained from the nearby dykes of dolerite. The angular blocks of stones needed a thorough preparation before detaching desired flakes. The cleaver-flake of Chirki-Nevasa tool-kit evidence use of Para-Levallois *(Fig.11)*. The form of raw material, thus seems to be one of the significant factors responsible for the predominance of unprepared cleaver- shaped flakes in the Nagarjunakonda industry and of the prepared and Levallois flakes in Chirki-Nevasa industry.

C. Techniques for modifying edge & tip of tools

Careful and controlled flaking was done to modify the edge and tip of artifacts throughout the Palaeolithic period, which is referred to as *retouching*. This effort was particularly needed to give shape, increase sharpness of the edge and even blunting the edge of a flake or a blade. Various types of scrapers and pointed implements were made by retouching. Retouching during the Palaeolithic period was performed by direct percussion technique and by using both stone hammer or soft and cylindrical hammer. These are categorized within two types e.g., the low angle retouch and the high angle retouch. Low angle retouching was done primarily during the Lower and the Middle Palaeolithic phases when edge of flake needed to be sharpened. The angle of the retouched portion in this case range around 60^{o} - 70^{o}. But, with the prevalence of blade technology when both the edges were sharp there was a need to blunt one of the edges for hafting purposes. It was due to this

requirement that retouching at high angle (more than 70° - 75°) had to be initiated. During Upper Paleolithic various forms of backed blades or knives were made by high angle retouching or blunting. In India though both the types of retouchings were done, the amount of modification of the form of edges were not a very general practice. With the result, our Palaeolithic tool-kits appear mediocre in comparison to the Middle and Upper Palaeolithic implement collections of Europe.

The bone and antler industry which had flourished during, the Upper Palaeolithic phase of Europe (Bordes, 1968, pp.147-166), is not well represented in India. Though there are a few claims for bone tools, these are either lost or if available do not evidence good workmanship. But, the specimen which has been reported from Gravel III of Belan, Uttar Pradesh, and referred to as 'Mother goddess figurine' (Misra, V.D. 1977, Pl.V) evidence good craftsmanship, but appears to be an isolated example of its kind. In correspondence with the paucity of bone craftsmanship, the Upper Palaeolithic collections in India, in general,lack presence of burins. Even when present this type is simple formed and much restricted in number (Jayaswal 1978, pp. 174 - 193).

It may be recalled that burin is a specialized implement form which was used for working and engraving bone, antler and ivory (Jayaswal, 1987, pp. 42 - 45). It may not be a mere coincidence that both burin industry and the bone/ivory craftsmanship flourished in Europe during upper Palaeolithic times.

II. Techniques Of the Mesolithic Period

The diagnostic tool group of the Mesolithic period, throughout the world has been identified as Microliths. The tiny artefacts of this category are characterized by two features. One that these are made on bladelet (micro-blade having breadth 12 mm or less). The other, that at least one of the edges of these specimens was deliberately blunted by high angle retouching. There are a group of implements in Mesolithic tool-kit which fulfil these two criteria. Microliths were made in geometric forms such as triangular and trapezoidal shapes, and non- geometrical forms, lunate or various types of a backed bladelets (*Fig.12*).

The provision for hafting (by blunting of edge) and the small size are so pronounced in case of microliths that the presumption hold good that this group was used in composite form, (putting together more than one tool) on a base of wood or bone (Jayaswal, 1989, vide *Fig.10*).

The technology of microlith making appears to be of local origin in India (Jayaswal, in Press). The appearance and the earliest existence of microliths in our area of study is in association with the fulfledged blade industries of the Upper Palaeolithic period. The techno-typological features borne by microliths indicate that this technocratic group was modification and development over the blade technology. The dimension of the blade element was reduced to form bladelets. Besides, the earlier tradition of modifying edge/edges at high angle was also adopted as an essential process for giving shapes to the implements. Besides, the beginnings of microlith making in central India is datable to circa twenty-fourth millennium B.C. The archaeological remains from Gravel III of the Belan-Seoti valley (Pant, 1982, pp. 101-102) and the Son valley (Sharma & Clark, 1983, p.

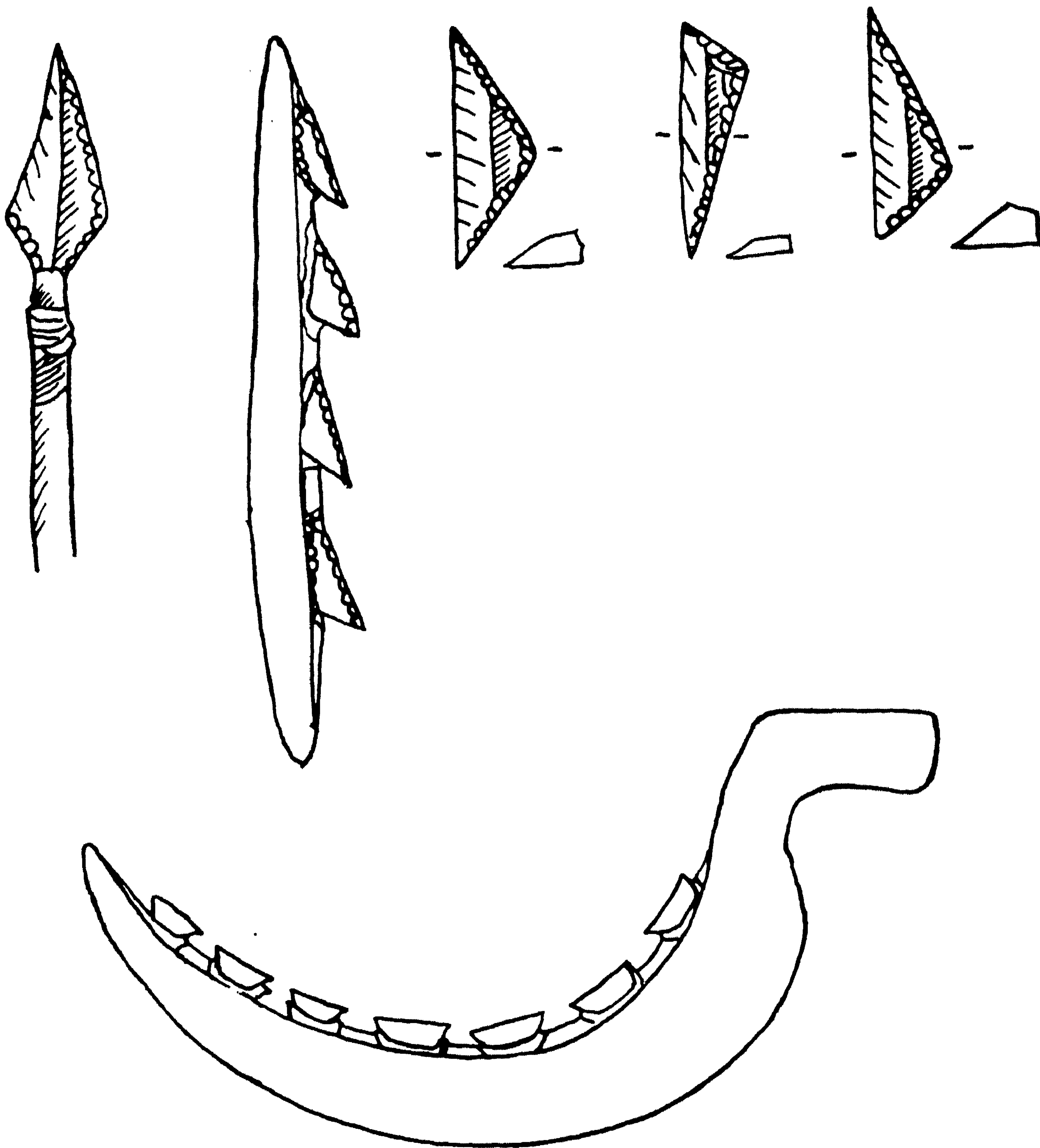


Fig.12. Microliths

287), indicate that the Upper Palaeolithic industries which are dated by the Radiocarbon method between 24,000 and 18,000 B.C. are associated with microliths. It is interesting to note that right from the beginning when pigmy tools formed only a small proportion (10%) of the tool-kit, the microlithic technology appears in developed form. But the implement forms are mostly non-specific. For, the microlithic group is dominated by backed- bladelets and presence of a few lunates. Such perfect geometric forms as triangle and trapeze are either absent or when present (triangles are generally found in this phase), these are in negligible proportion and mostly atypical forms (Pant, 1982, pp. 104-105). It may, therefore, be concluded that, making of microliths emerged in the last phase of the Pleistocene period. The technological trait seems to have developed from the blade industries and thus was innovation. Similar situation is also found in Europe where microliths

appear in the Upper Palaeolithic industries of the later Pleistocene epoch. The tool-kit of Magda-lenian culture is associated with microliths (Bordes, 1968, p.164)

Microliths predominate (up to 80% of the finished tools) all the Mesolithic industries of India, be it of 'Early' or 'Advanced' stage. Geometric forms particularly triangle, became more popular during Mesolithic times (Jayaswal, in Press). All the other remaining techno-typological features remained almost unaltered. It has also been shown by this author that microlithic technology continued to persist for a very long period in Central India. Undisrupted continuation of this technology is evident in the hills of Uttar Pradesh and Madhya Pradesh, even up to the Historical period (Jayaswal, In press). In this case, microliths existed as parallel technological trait with Neolithic, Chalcolithic and Iron Age cultures. It was observed that though there is a gradual decrease of frequency of microliths from the Mesolithic to the Neolithic and the Chalcolithic periods, there is a sudden fall in the proportion of microliths during the early Historical period (Iron Age).

Besides, the general techno-typology of the microlithic toolkit remains somewhat unchanged during the earlier three culture stages, while there is marked increase in trapeze during the Iron Age.

III. Techniques of the Neolithic Period

The lithic technologies of the Palaeolithic and Mesolithic times are marked by a process of development in which two tendencies were pronounced. One, the economy of labour and raw material, which can be seen in terms of the Levallois technique to the blade detaching technique. In case of the latter, expenditure of very limited time and wastage of stone was able to produce much larger and sharper working edges, than was acquired by the flakes obtained by Levallois techniques. Second, during the course of this development the size of implements was gradually decreasing, the culmination of which can be seen in the case of the microliths. Contrary to this the lithic technological attainment appears to reverse back to the earlier technological stage during the Neolithic period. For instance, not only large to very large size tool making was initiated, which compares well with Acheulian tools of the Lower Palaeolithic times, but also input of laborious processes were being involved. The Neolithic technological innovation is marked by the Ground stone tools or axes. Many forms of axes, chisels, picks, hoes, were made which together form tool-kit of a carpenter. Making of a typical Neolithic axe involves three stages of working (Sankalia 1964, pp. 79-82).

In the first stage the basic form of the implement is chipped by direct percussion method and using stone hammer. In the second stage, the prominent ridges appearing from the earlier flaking are removed by pecking method. In pecking method very small flakes are carefully detached so as to bring down the raised surfaces of the tool. The third process is very 'lengthy and tedious, in which the surface of the tool is ground. Grinding process was performed on a stone anvil by sprinkling sand and water and rubbing parts of the implement one by one (*Fig.13*). This technique is so characteristic of Neolithic period that the tools are referred to as 'ground stone tools'. The aim to perform this process was to provide toughness

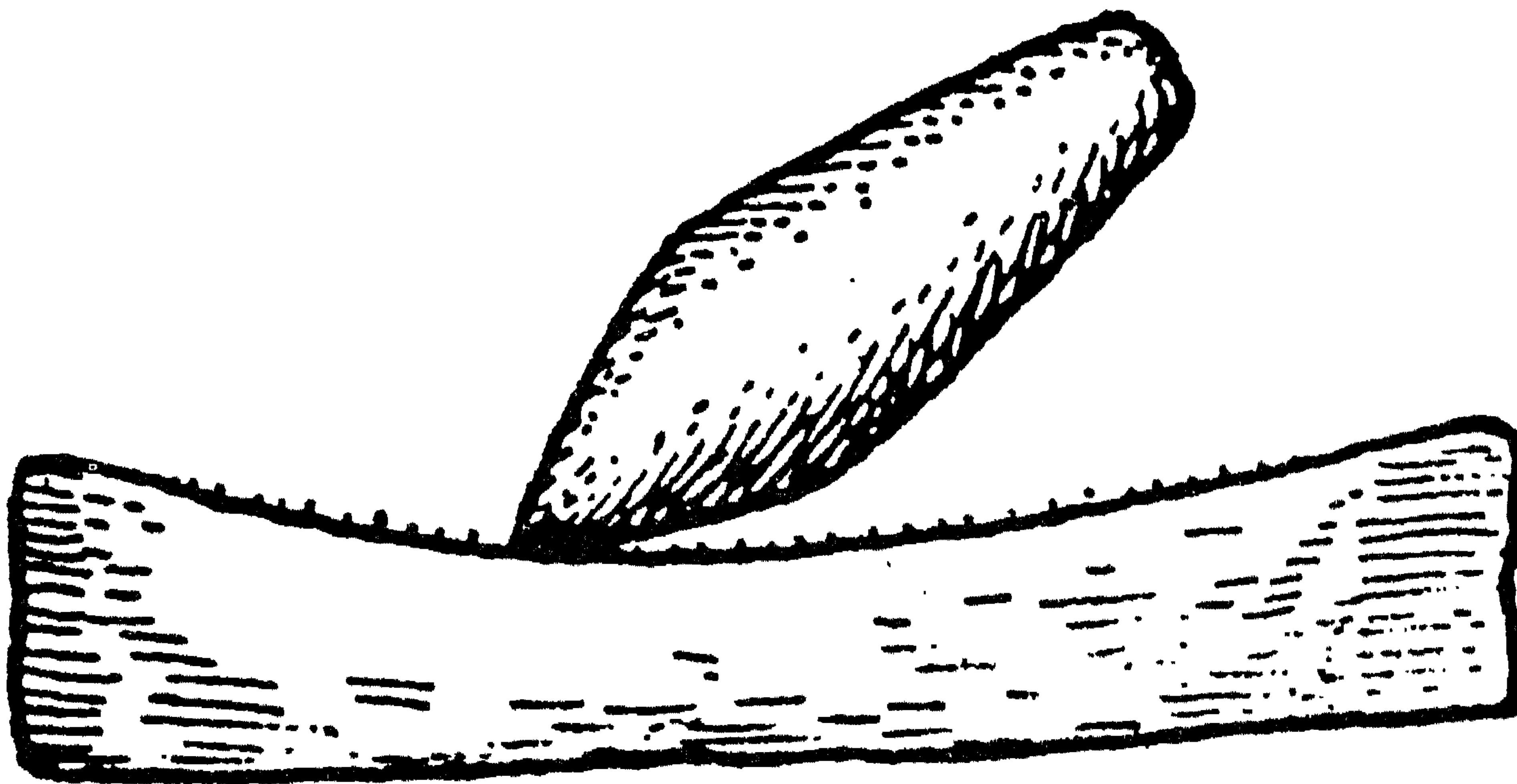


Fig.13. Method of Grinding Stone Implements

to the implements (Jayaswal, 1992). Neolithic implements have been obtained from various parts of the Indian sub-continent. In the north, Kashmir valley has Burzoham group of sites, where along with the axes, chisel, pick and hoe are common types.

In Uttar Pradesh and Bihar, the Neolithic tool-kit comprises small triangular axes as the major type, along with a considerable proportion of quaerns and mullers and microliths. The east Indian Neolithic complex is characterized by shouldered axes. While the south Indian sites which have concentration in Karnataka, Andhra and Tamilnadu, have axes similar to the Uttar Pradesh and Bihar region. Though techno-typological features of the Neolithic tool-kit of India compares well, in general term with other parts of the world, particularly West Asia, the cultural *debris* of this region is of later date.

Except for a couple of dates from Koldihwa (Sharma et al. 1980, pp. 198-199), which are early, but debatable, all the other dates of the Indian Neolithic horizons belong to the bracket of fourth to second millennium B.C. (Jayaswal, 1992).

Bone and antlers were used as another preferred medium for implements during the Neolithic period in India. Various types of pointed tools were made (Thapar, 1985,p.30). While examining the osteological remains from one of the Neolithic-Chalcolithic sites excavated by our department it was possible to make some observations on the bone utilization tendencies and making processes by us (Thakur & Jayaswal, 1991). The Senuwar collection of bones showed that the suitable broken bones which had originally formed part of food refuge, were utilized as tools, with little or without any alteration. Two types of natural morphology were exhausitely exploited by Senuwarians of the Neolithic times. Firstly, the original bone forms in the shape of chisel-like edge and thick and broad tubular faceted parts as butt, were found suitable for use.

Secondly, natural breakage pattern of bone, in pointed form was also picked up for use. These conclusions were derived at by conducting micro-wear studies on specimens. It was also found that the number of finished tools was very limited in the Neolithic phase (*Fig.14*). The tools were made out of the long limb bones of

animals. The cortexed part or the outer part of the bones was suitable for making points and needles etc. The cancellous portion which is placed in the middle part of the bones needs to be avoided with a view to retaining toughness.

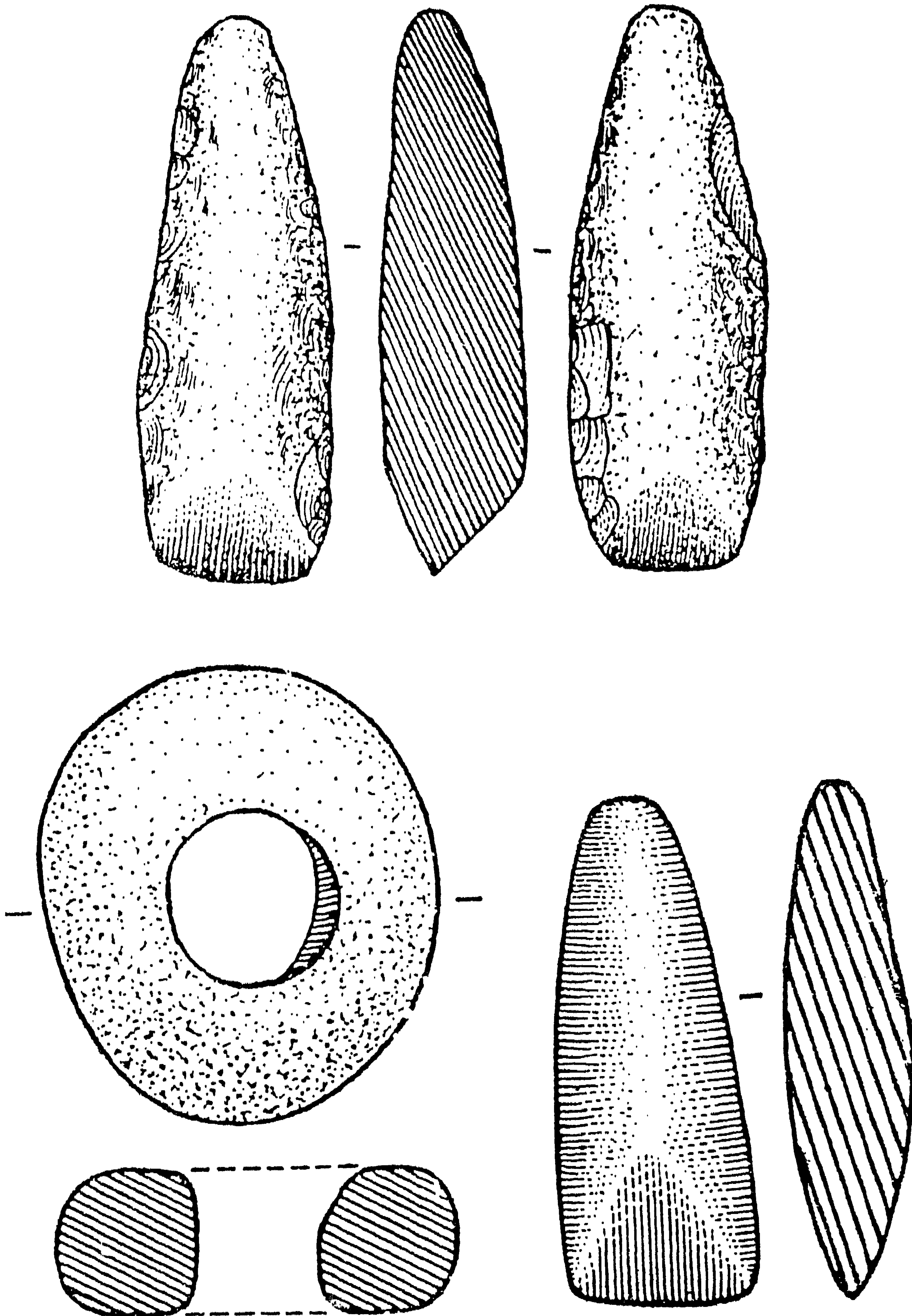


Fig.14. Adze, Mace-head & Axe of the Neolithic Period

This part was only usable for the socketed tools. The chiselling and grinding were the processes through which a typical bone implement was made.

The above description of the Stone Age technologies in India suggests that though the evidence which has been accumulated so far suggests that the occurrences and practices of various techniques in this region also follow the general trend of technological attainments, yet many of the techniques are less prevalent or not well mastered. Also the date for the origin and spread of some of the lithic technological trends are comparatively later than some other regions of the world.

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Bronze Age Technology

D.P. AGRAWAL and MANJU PANT

Introduction

Our analysis is based on the archaeological evidence now available for the period from 3000 to 1000 B.C., with special emphasis on copper technology. In the Indian subcontinent, this period was characterized by the use of copper, although stone blades continued to be used. The subcontinent did not have a uniform unilineal socioeconomic development during this period and therefore some of the terms have special connotations in Indian archaeology.

The Harappan, the Chalcolithic, and the Copper Hoards cultures were the three main copper-using cultures. The Harappan culture was a fully urbanised culture and is generally excluded from the Chalcolithic group. The latter group includes exclusively non-urban cultures whose economy was akin to the non- metal-using Neolithic cultures of the South. The third group is called the Copper Hoards culture, so named because most of the finds were found in hoards.

Indus Civilization

The Indus civilization or Harappan culture (named after the first discovered site, Harappa) is well known for its uniformity and standardization in weights, measures, ceramics, architecture, extended over more than a million square kilometers, an area larger than that of Pakistan today. It spread in the west to Sutkagendor (Makran), in the east to Alamgirpur (Uttar Pradesh), to Rupar in the north and to Bhagwatrav in the south (Gujarat). Whether this uniformity indicates an empire or a trading zone can only be guessed.

Bead factories have been discovered at the Harappan sites of Chanhudaro (Mackay, 1943) and Lothal (Rao, 1973). Beads were made of agate, carnelian, faience, shell, terracotta, gold, silver, and steatite; beads with inlay work and etchings were probably exported.

A highly standardised system of weights and measures was evolved by the Harappans. Two systems of measurement were used : cubits and a long foot. A

cubit was about 52 cm (52.5-52.8cm) and the long foot was 33.5cm. Graduated scales with decimal graduations (upto 1.7mm) have been reported. The cubical, stone weights followed a binary system (1, 2, 1/3 × 8, 4; 8, 16, 32 upto 12800) in the lower denominations, and the traditional Indian ratio of 1:16 (1 rupee is equal to 16 annas) may derive from this. The unit weighs 13.625 gm. Higher weights follow a decimal system with fractional weights in thirds. The accuracy of these weights throughout the Harappan territory is quite remarkable.

According to the texts, Meluhha (identified with the Harappan zone) exported a variety of timbers, copper, gold dust, lapis lazuli, carnelian and other stones, ivory figurines of birds and monkeys, etc. Most of these items were available from India, except perhaps lapis lazuli. Baluchistan, Afghanistan, Oman and Rajasthan all have copper mines. Sixteen copper furnaces from Harappa, the copper workshops in Lothal, and the large quantities of copper-oxide ore from a brick-lined pit at Mohenjodaro all suggest that copper metallurgy was a developed craft in the Indus civilization. Placer gold is found in the streams of Punjab and Kashmir and may have been the source of the gold dust.

Wheeler's (1968) time bracket of approximately 2500-1500 B.C. for the Harappan culture was based upon the discovery of Harappan objects in Western Asian archaeological contexts and the Mesopotamian artifacts in Harappan sites. Fairservis (1967) found it hard to accept a millennium-long monotony for the Harappan culture and preferred a range of about 2000-1500 B.C. Allchin and Allchin (1968) proposed that the period around 2150-1750 B.C. would better support the evidence. We, however, have suggested periods of 2300-2000 B.C. for the nuclear regions and 2200-1700 B.C. for the peripheral zone of the Harappan culture (Agrawal and Kusumgar, 1974).

There is, however, more definite evidence for contacts between Mesopotamia and the Indus during the Sargon of Agade (around 2350 B.C.) and Isin-Larsa periods (about 1900-2000 B.C.). Disk-shaped beads of gold and silver with axial tubes have been reported from Akkadian and Troy II levels.

Analyzing the data on contacts between Mesopotamia and the Indus, Buchanan concluded :"The Mesopotamian evidence, therefore, does not require a date of for the mature Indus civilization much, if at all, before the 23rd century B.C. It would be surprising if it lasted more than 300 years. We think that this is a fairly balanced conclusion from the archaeological evidence" (1967 : 107).

A fairly large number of radiocarbon dates is now available for Harappan sites (Agrawal and Kusumagar 1974), and there are also ^{14}C dated sites like Balakot, Damb Sadaat, and Kot Diji with both pre-Harappan and Harappan deposits. Harappa itself has few ^{14}C dates nor do we have any dates for the lower levels of Mohenjodaro. Radiocarbon dates in the main Indus region show a spread of about 4250-3950 B.P., which agrees well with the archaeological evidence from Mesopotamia.

In the peripheral zone, Kalibangan in Rajasthan has been exhaustively dated. Considering only those samples that were protected from more recent contamination by a good soil cover, we find that TF-607 and TF-608 date the beginning of the Harappan culture at that site around 4150 B.P. and that TF-143, TF-149 and TF-946 date the upper levels to around 3700 B.P. Lothal provides a

quite consistent set of dates giving a minimum spread of 4050- 3650 B.P. (obtained by adding one standard deviation on either side). In view of the thinness of the occupational deposit at Lothal, compared to the other Harappan sites, we prefer the minimum time spread of around 4050-3750 B.P. This bracket is further confirmed by the radiocarbon dates from Surkotada, also in Gujarat, where a bracket of 4150-3750 B.P. covers the total Harappan occupation and is in conformity with the dates from Rojdi. Thus, a comprehensive bracket of 4250-3650 covers both the nuclear (main Indus) and the peripheral Harappan timespreads. (*Fig. 1*).

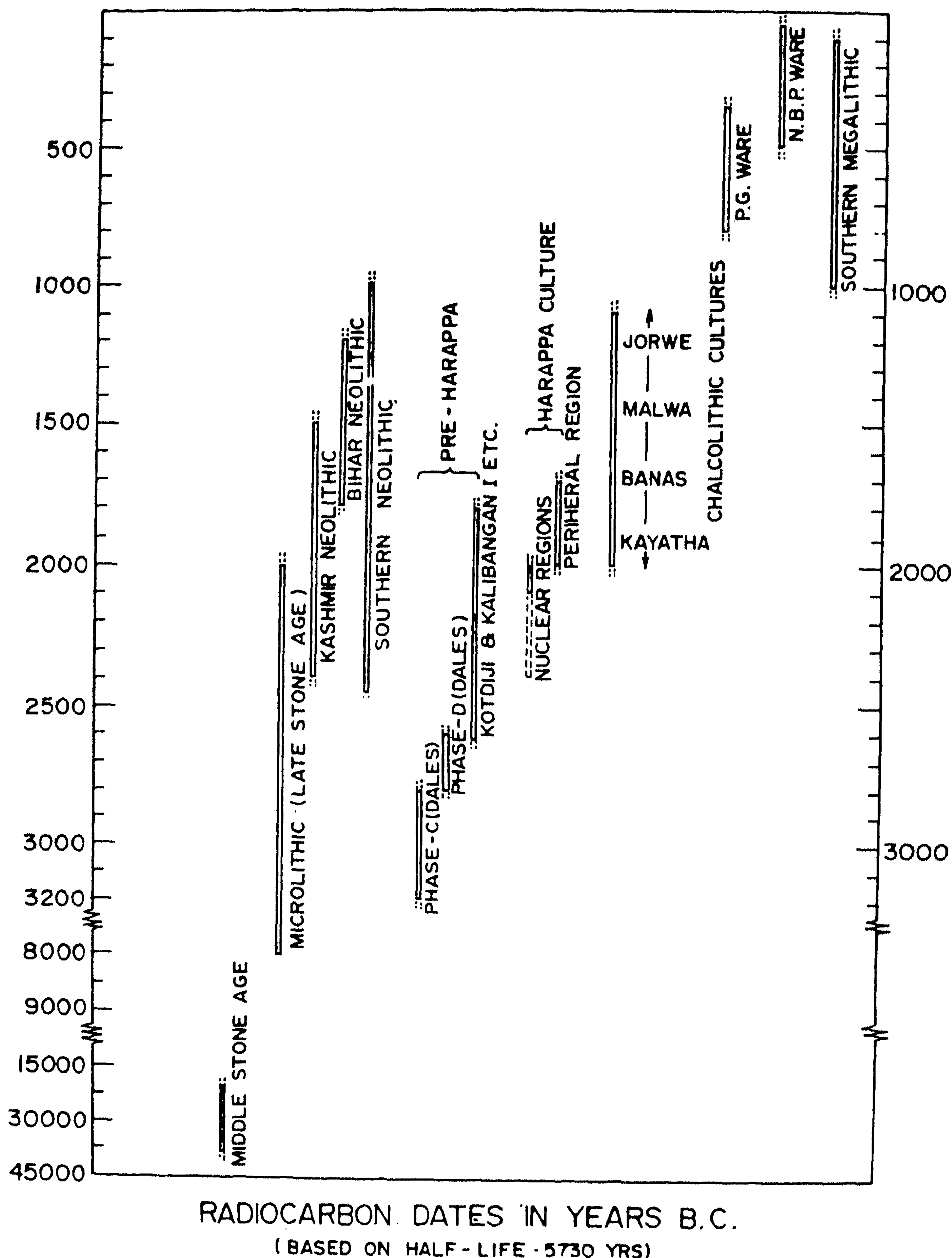


Fig. 1 Chronological time spreads of different stone and metal using cultures in India

Metal Technology of the Harappans

Before we discuss copper artifacts and their technology, it will be useful to mention the types of ores and their main locations in India. The main Indian copper minerals are (a) chalcopyrite ($CuS.Fe_2S_3$), (b) chalcocite (Cu_2S), (c) malachite ($CuCO_3$). $Cu(OH)_2$, and (d) azurite (2 $CuCO_3.Cu(OH)_2$). The major copper mines are located in the 80 km long Khetri belt in Rajasthan and the Singhbhum copper belt in Bihar, which is 130km in length. Other important deposits occur in the districts of Guntur, Arcot, and Kumaon (Brown and Dey 1955; Agrawal 1971). Sources in Baluchistan, such as Shah Maksud and Kalih Zeri, have also been mentioned as probable mines for Harappan copper (Sana Ullah 1931).

Pre-Harappan (or Early Harappan) contexts are generally poor in copper; from the pre-Harappan levels of Kalibangan, for example, we have three artifacts, including a *parasu* (hatchet). Only from Nal, in Quetta, is there a richer repertoire composed of knives, bangles, and axes.

The Harappans were far richer in copper and also in copper tool types, although they continued to use chert blades. They had flat celts, knives, arrowheads, spearheads, chisels, razors, fishhooks, saws, drills, etc. (*Fig. 2*), in addition to vessels and metal figurines. It may be noted here that tubular drills, true saws, and needles with eyes at the pointed ends are contributions of the Harappans to the world of instruments. The Harappans were the only people in India who used metal lavishly for vessels, including a variety of vases.

Most of them seem to have been made in two parts, the bottom and the top, and then joined together. For vessel fabrication they used *sinking, raising* and *lapping*, and for joining metal they used *running* on and riveting techniques (soldering was used only for noble metals). Metallographic examination shows that they resorted to open and closed casting, slow cooling of casting, annealing and cold work (Agrawal 1971; Agrawal et al. 1978b).

Small animal and female figurines (for example, see *Fig.3*) were cast by the *cire perdue* (lost wax) process (*Fig. 4*), although none of the Harappan moulds is as ornate as the Chinese, nor as intricate as the Mesopotamian examples. A number of axes from Chanhudaro and Mohenjodaro show puckered surfaces, indicating that they did not always use *green poling* in open moulds; the use of green branches for poling in molten copper releases hydrocarbons which reduce the oxides, thus avoiding blowholes.

Pure copper is not a hard metal, but it can be made harder through beating (cold work). Too much cold work, however, makes the edge brittle and it then requires heating (annealing) to make it ductile again. Alloying copper with arsenic or tin increases its hardness considerably, and today we know that copper should be alloyed with up to 4-5% arsenic and 8-12% tin for maximal ductility and hardness. We have now more than 200 analyses of Harappan artifacts (Agrawal et al., 1978b), which indicates that only 23% were alloyed with tin, 12% with arsenic, 8% with lead, besides a smaller percentage with an admixture of these elements. It should be noted that the Harappans used both Sn and As alloying and the Chalcolithic cultures exclusively tin alloying (*Fig.5*). In an effort to locate copper artifacts, we find a hatchet at Khurdi (*Fig.6*) similar to one found at Kalibangan. As regards

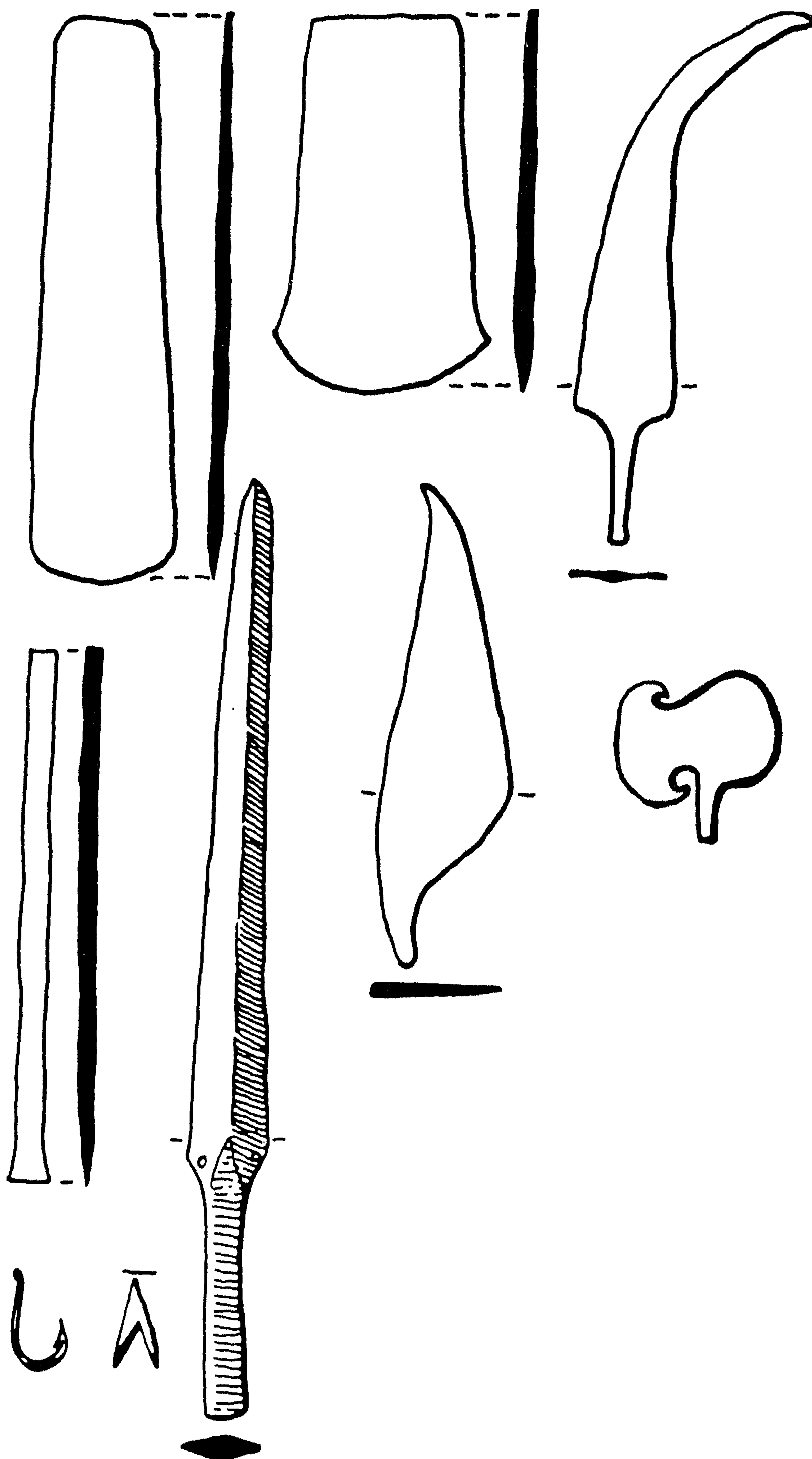


Fig. 2 Main Harappan metal artifact repertoire

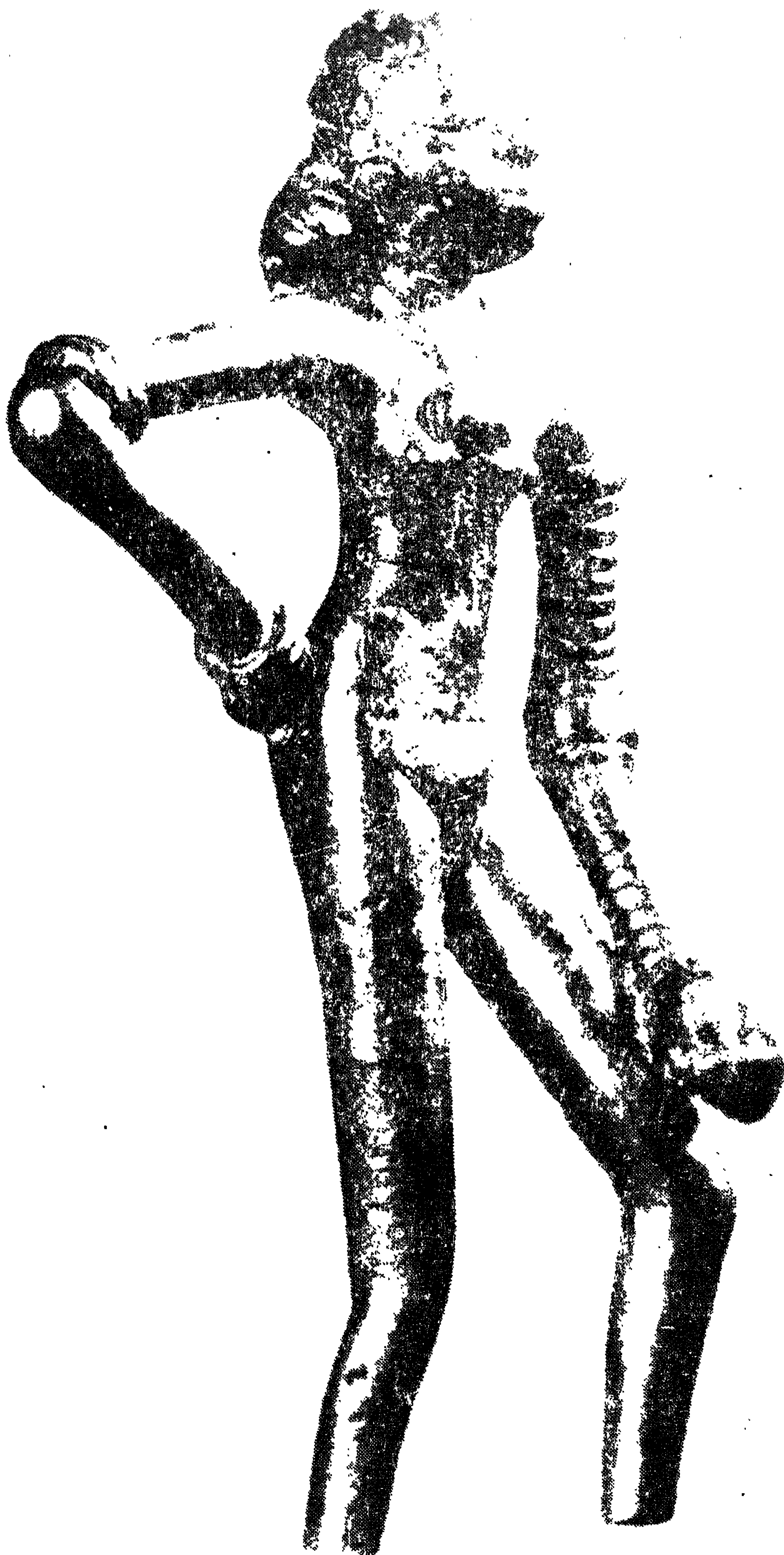


Fig. 3 Bronze image of a dancing girl from Mohenjodaro indicates the use of cire perdue technique

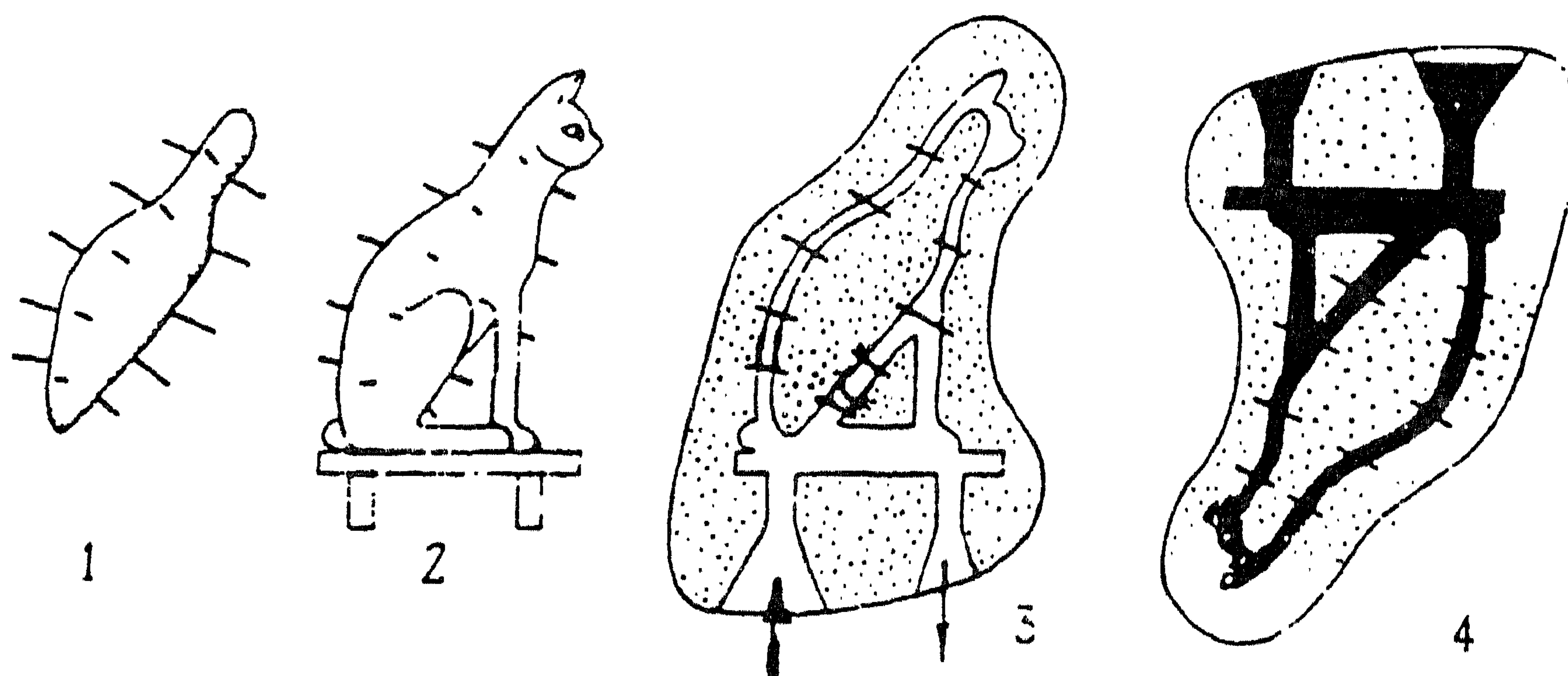


Fig. 4 Cire Perdue casting method explained: Stage 1. The terracotta core with pins.; Stage 2. Wax model of the cat enclosing the terracotta core.; Stage 3. Terracotta covering over the wax model; the arrows indicate inlet and outlet for the molten metal. Stage 4. The molten metal washes out the wax model and replaces it with the metal. The casting is allowed to cool and the clay covering is broken to uncover the bronze figure

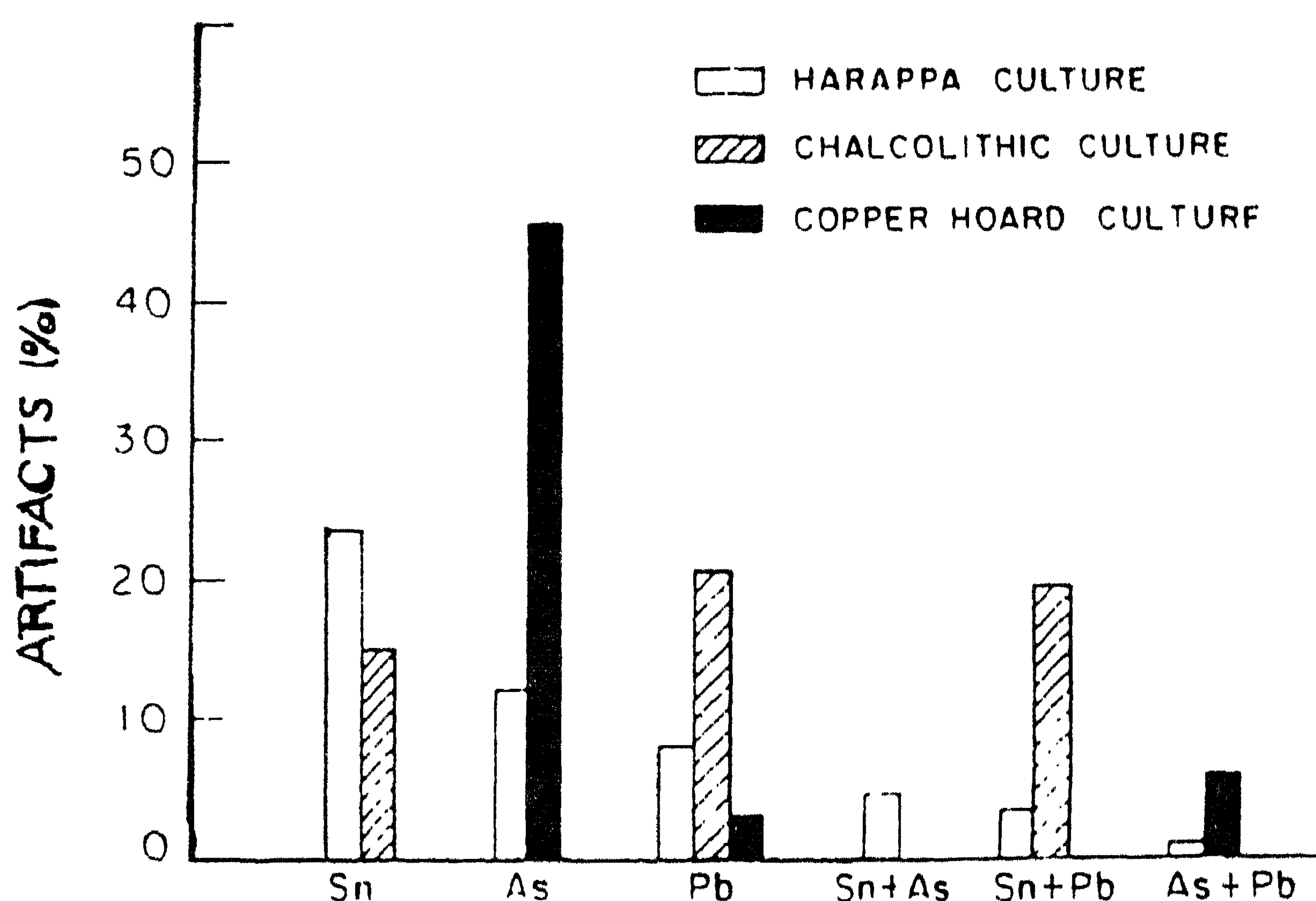


Fig. 5. Histograms of alloying patterns of protohistoric cultures. Note that only the Harappans use both tin and arsenic alloying. The Chalcolithic cultures use only tin and the Copper Hoard culture only arsenic alloying. This pattern shows that these three technologies were distinctive

copper sources used by the Harappans, a large number of ancient copper workings have been radiocarbon dated (Agrawal et al, 1976), but none of the dates so far is older then 3150 B.P. With further work, older working are expected to be found. We have also tried to use comparisons of trace-impurity patterns between ores and artifacts. In both the Khetri (Rajasthan) ores and Harappan artifacts, gold is absent, but a number of other trace elements (silver, iron, arsenic, antimony, lead, bismuth, tin, nickel, zinc, manganese, cobalt, aluminium, copper molybdenum, titanium, magnesium, and vanadium) are present, suggesting the use of the Khetri ores by the Harappans. This method is not foolproof, and it is therefore hoped that results can be reconfirmed by the use of lead isotope ratio comparison between ores and artifacts and also by the techniques used by Chernykh and Tarakhova (personal comm.). Circumstantially, Khetri mines of Rajasthan are likely to have been exploited by the Harappans, because they are found in roughly the same areas.

Chalcolithic Cultures

The so-called *Chalcolithic* cultures are characterized by the use of stone and copper artifacts, but metal is rare, and the cultures are non-urban. Traditionally, the non-Harappan cultures of the second millennium B.C. are included in this category.

We discuss here the main cultures belonging to this group, starting from south-eastern Rajasthan and covering Central India and Maharashtra. The Ocher-Colored Pottery cultures and the Copper Hoard culture of the Gangetic valley are discussed in the last section. During the second millennium B.C. the rest of the subcontinent was occupied either by Neolithic cultures, or by the Indus or Indus-related cultures.

The Banas Culture

More than fifty sites of the Banas culture are known from the valleys of the Rivers Banas and Berach in southeastern Rajasthan, but the only excavated sites are Ahar and Gilund in Rajasthan and Kayatha in Madhya Pradesh. The available ^{14}C dates (*Fig.1*) suggest a bracket of about 3950-3350 B.P. for this culture (Agrawal and Kusumgar, 1974).

In contrast to the arid and flat western region where the only relief is provided by extensive sand dunes, Rajasthan is greener and more hilly in its eastern part and the Banas and the Chambal are almost perennial rivers in this area. Udaipur and its environs form a large basin, enclosed by hills, with a single broad opening on the northwestern side. Ahar, the type site of the Banas culture, is located in this basin, with good soil, fair rainfall, and plentiful game even today.

There are schist and quartz outcrops, which the Aharians used in house building, and copper ores for their tools. It is curious that at Ahar only copper was used and no stone blades, while the Banas culture had a developed blade industry at Gilund, a mere 80km away, and also at Kayatha in Madhya Pradesh. Even copper, however, is not abundant, as only five axes, one knife blade, one sheet, a bangle, and two rings have been reported from Ahar.



Fig. 6. Copper objects from Khurdi (in fact, Kurada), Rajasthan. These are generally included under the Copper Hoards but are typologically different from the main Copper Hoard group

The Kayatha culture, discovered by Wakankar at Kayatha on the River Kalisindh, a tributary of the Chambal, is the earliest Chalcolithic culture in Central India and is radiocarbon dated between 3950 and 3750 B.P. (*Fig. 1*). This culture is mainly confined to the Chambal Valley, but, out of approximately 40 known sites, only Kayatha has been excavated (Ansari and Dhavalikar, 1975).

The Kayathans seem to have been rich in copper; 28 copper bangles were recovered from a single pot. The two copper axes with sharp cutting edge and a lenticular section are the finest examples in the Bronze Age of India; they were cast in a mould, unlike the later Chalcolithic artifacts, which were merely hammered out of sheets. A chisel is also reported from Kayatha.

The Malwa Culture

The Malwa Culture is.characterized by Malwa ware (a buff-or orange-slipped pottery painted in black), by copper or stone artifacts, and by small settlements of wattle-and-daub huts. It was spread over the Malwa region (as were also the Kayatha culture and to some extent even the Banas culture), and also extends into Maharashtra.

The excavated sites of Eran, Nagda, and Navdatoli are in Madhya Pradesh, and Inamgaon is in Maharashtra. The Malwa culture has a radiocarbon range of around 3650-3350 B.P. (*Fig. 1*). Navdatoli is not only the site par excellence of this culture but is also well published (Sankalia et al, 1958, 1971). In the local dialect, Navdatoli means "village of the boatmen", and the site is situated on the southern bank of the River Narmada; the site of Maheshwar, also with extensive traces of settlement, is situated on the opposite bank. The site presents beautiful panorama of the tall Vindhyas in the north, the low Satpura hills in the south, and the wide expanse of the Narmada in between with considerable alluvial deposits on either side of the river. The selection of the site clearly shows that the Chalcolithic technology was adequate only for fresh alluvium and was not capable of dealing with the black cotton soil. Each household made its own stone tools of a milky chalcedony, using the crested- ridge technique.

The use of copper is evidenced by flat celts with convex cutting edges, arrowheads, spearheads, chisels, and a mid-ribbed sword, which was cast; all other artifacts were probably hammered to shape. Copper beads, bangles and rings are also found.

A hoard of massive copper animal figures of a rhinoceros (*Fig. 7*), an elephant (*Fig. 8*), a buffalo (*Fig. 9*), and a bull chariot driven by a man (*Fig. 10*), all mounted on wheeled platforms, was accidently discovered near Diamabad and has been ascribed by some scholars to the Chalcolithic phase.

Each object, however, weighs several kilograms and to use such a quantity of metal for non-utilitarian artifacts seems unlikely for a Chalcolithic phase. They can only belong to historical period.

The Jorwe Culture

Maharashtra, the home of the Jorwe culture, is composed mostly of the Deccan plateau, and only the river valleys have open plains with rich soil cover. Annual

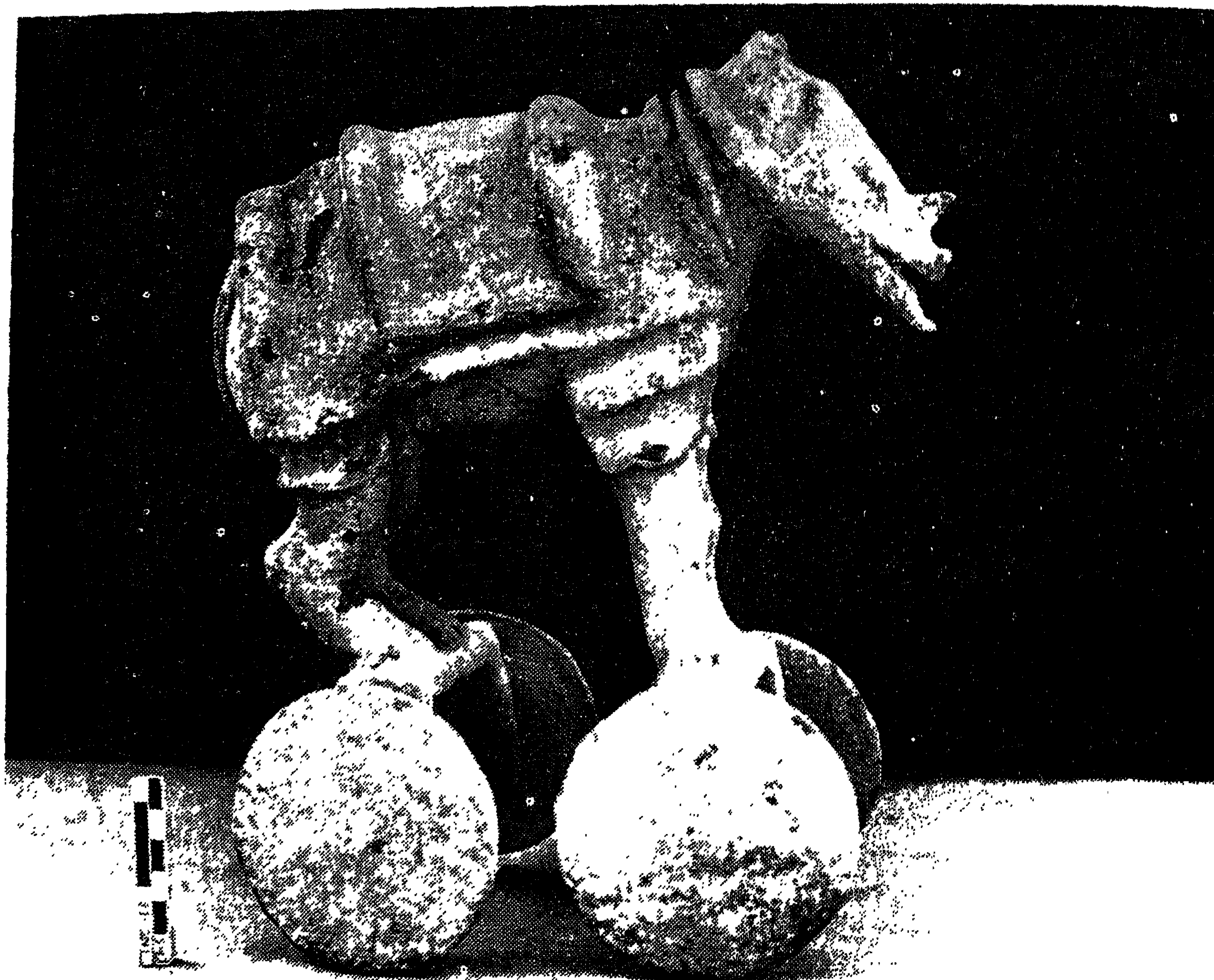


Fig. 7. Daimabad bronze rhino on wheels. For discussion see the text

rainfall is in the range of 50-100cm, but it varies greatly from year to year and droughts are frequent. The vegetation is xerophytic (examples include acacia, tamarin, and *caparis*). The vast alluvial stretches in the Pravara-Godavari basins have more than 3m of fertile soil, and the main Jorwe culture sites are located on these alluvial flats. Smaller Jorwe sites seem to be concentrated around major centres. The former usually have only a few huts and an area of 2-3 ha whereas a major centre, such as Prakash in the Tapti Valley, Inamgaon in the Bhima Valley, and Diamabad in the Godavari Basin, may cover 20 ha. Excavated Jorwe sites include Inamgaon, Theur, Songaon, and Chandoli in Poona District, Bahal in Jalgaon District; Prakash in Dulia District; and Jorwe and Nevasa in Ahmednagar District (Dhavalikar 1979b).

A variety of materials like agate, carnelian, jasper, chalcedony, gold, copper, and ivory were used for making ornamental beads; copper anklets and gold ear ornaments have also been reported.

A pair of tongs and a crucible indicate local gold working, although the gold itself may have been imported from Kolar. Copper was also used to make axes, chisels, knives, fishhooks, beads and bangles. A smelting kiln has been identified at Inamgaon.



Fig. 8. Daimabad bronze elephant. Height: 36.5cm. For discussion see the text

Chalcolithic Metal Technology

The Chalcolithic cultures depended on stone artifacts, rather than on copper, to a greater extent than either the Harappans or the Copper Hoards people. On the whole, about 17% of Chalcolithic artifacts show tin alloying (see *Fig. 5*), but the range varies considerably: at Ahar, only pure copper was used; a Jorwe axe has only 1.7% tin; a Nevasa chisel has 2.7% tin; at Navdatoli, the range of tin alloying is 3-5%; the highest tin (12.8%) recorded was in an axe from Somnath. Unlike the Harappan and Copper Hoard cultures, Chalcolithic groups did not alloy with arsenic. For better fusibility, lead alloying was more common; 20% of the artifacts contain lead.

A few artifacts have been examined metalographically (Agrawal et al, 1978b), Pathak and Medhekar 1955). An axe from Chandoli shows casting fins all over the surface. Although equiaxial grains and the absence of coring indicate a slow cooling of the cast, yet the holes on the surface show that the molten metal was not "green poled". An axe from Somnath shows evidence of cold work and annealing, and specimens from Navdatoli and Ahar indicate a knowledge of casting and annealing. The report of "glassy" slag at Ahar indicates local smelting.

Hegde (1965) has spectroscopically examined several Chalco- lithic artifacts and compared their trace impurities with those of the Khetri copper ore. He finds a close similarity between the two, thus indicating the possibility of the Khetri ores



Fig. 9. The bronze buffalo from Daimabad. For comments see the text

having been used by the Chalcolithic cultures. The Khetri mines are quite close to Ahar.

The most beautiful examples of the Chalcolithic craft are the cast axes from Kayatha. Most Chalcolithic metal artifacts, however, are of simple, non-diagnostic types. The main forms are beads, nails, rods, wires, fishhooks, rings, flat celts, and daggers. The Chandoli dagger has been compared with the antennae- hilted sword from Fatehgarh, but we consider that there are very important technological differences between the two. The total length-to-blade ratio in the Chandoli-dagger is only 1 6, compared to 5 in the Fatehgarh example, the tang was cut with a chisel and the incipient antennae so produced do not compare at all with the 10-15cm long, cast antennae of the Copper Hoards types.

The Ochre-Coloured Pottery and the Copper Hoards Cultures

The third important group of copper-using cultures is the Copper Hoards culture, and there is some circumstantial evidence to associate it with the Ochre-Coloured Pottery (OCP). At Saipai the OCP sherds included those giving off ocherous colour on rubbing, those with intact red slip and some with black, painted designs or incised decoration. The site also yielded rubbers, querns, a chert and a chalcedony blade, a burnt brickbat, chunks of burnt clay with reed impressions, bones of *Bos Indicus*, a copper harpoon, and a hooked spearhead (Lal 1972).

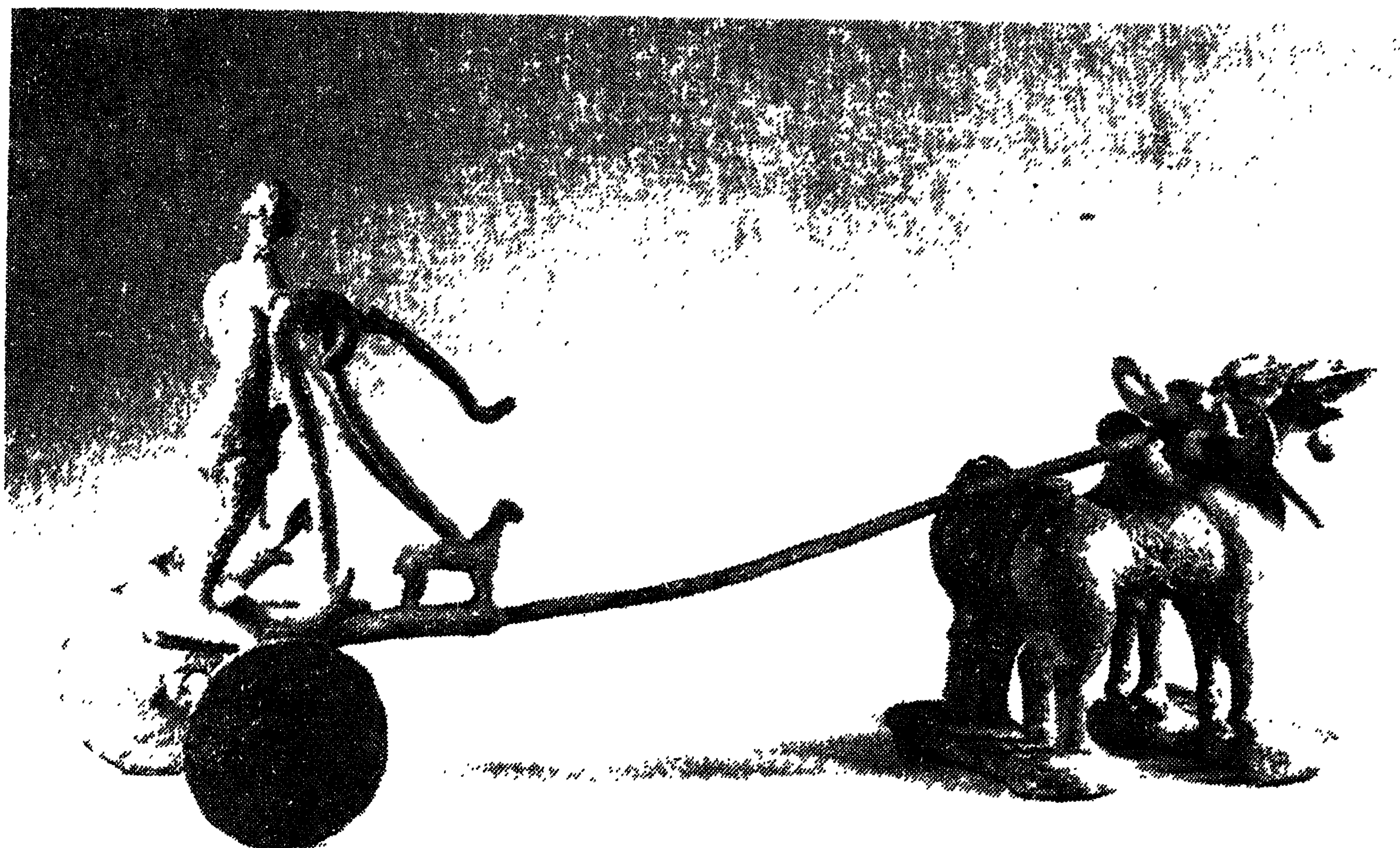


Fig. 10. A chariot with its driver found near Daimabad. It has been suggested that it is a late Harappan artifact. The author does not agree with this view as explained in the text

It is difficult, however, to believe in the association of the Copper Hoard implements with the pottery at Saipai, and, with its spouted, handled and black-painted vessels and chert blades, Saipai appears to be quite unique. Moreover, the Copper Hoard artifacts have generally been found in caches rather than individually, so that the occurrence of only stray tools at Saipai raises doubts. I therefore feel that at present the association of the OCP and the. Copper Hoard should be treated only as provisional.

The Copper Hoard Culture

Most of the tools of the Copper Hoard culture (*Fig. 11, 12*) have been found in hoards or caches, mainly from Uttar Pradesh, Bihar, and Madhya Pradesh. Since most of the artifacts were chance finds, there was no control of a definite associated assemblage. As a result, finds from such far-flung sites as Shalozan in north-western Pakistan, Bhargrapir in Orissa, and Kallur in the south have been included in the Copper Hoard culture zone. A wide variety of types of tools was included in this amorphous collection: rings, a variety of celts, trunnion axes, anthropomorphs, harpoons, swords, double-edged and socketed axes, and so on. Naturally, such an odd assortment of tools have given rise to a plethora of hypotheses, and it fell to Lal to bring some order to the Copper Hoards.

In a brilliant analysis, he showed that a number of types (such as the Fort Monroe sword, axe-adze, socketed axes, and trunnion axes) were confined to the north-western part of the subcontinent (now Pakistan) and never occurred in the



Fig. 11. Two shouldered axes in bronze from village Itawa, Dist. Varanasi



Fig. 12. Three typical Copper Hoards artifacts from Bisauli, Dist. Badaun. Fromn left to right: barcelt, anthromorphic figure, a harpoon

Gangetic doab. Other types of artifacts (such as antennae- hilted swords, anthropomorphs, harpoons and barcelts) were concentrated mainly in the Gangetic doab.

Lal also showed the significant technological differences between the Koban examples (compared by Heine Geldern to prove his Aryan equation) and the antennae swords (Lal 1951: 20)

Following Lal,the distinctive types that can be included under the Copper Hoard category are: flat and shouldered celts (*Fig. 11*) antennae swords, harpoons, antrhopomorphs, hooked swords, and double-edged axes (*Fig. 12*). The last type has been reported from Bhagrapir (Orissa), where, although they are up to 40cm wide, their thickness is less than 3mm; they could not therefore have been used as tools. Their association with the main Copper Hoard types is, in any case, doubtful. The hooked swords seem to have parallel elsewhere, but closer examination reveals the distinctive features of the Copper-Hoard-associated hooked sword: in the apparently similar Harappan examples, a hole is provided for hafting and not a hook; in the Chalcolithic example from Navdatoli, there is hardly any median ridge, nor any hook. Moreover, the hooked sword has been found in association with such distinctive Copper Hoard types as anthropomorphs, antennae swords, and harpoons from Bahadurabad, Sarthauli, Fategarh, and Niori (all in Uttar Pradesh).

Anthropomorphs have been identified as ritual objects. We examined several specimens and have found three main features: externally sharpened and in-curved forearms, plain hindlimbs, and a thickened head (*Fig. 12*).

We have proposed their possible use as missiles to kill birds: the sharp arms could cut the bird; the thick head could stun it; and the in-curved arms could entangle and bring it down. When thrown, a replica of an anthropomorph travelled in a whirling fashion and followed a trajectory not unlike that of a boomerang (Agrawal 1969).

Sankalia (1974) has objected to this hypothesis on the ground that such a device would be too complicated to have been used by primitive people. The boomerang, however, was not invented by civilized people.

Rao (1973a) discovered a fragmentary copper piece with a convex end and two broken side lugs (*Fig. 13*) in the Harappan levels of Lothal, and compared it with the anthropomorphs from the doab. If it had had longer arms like those of the Copper Hoard examples, however, it would not be mechanically feasible for it to break so near the body (Agrawal 1971:192). It should also be noted that in the whole range of the Harappan artifacts, this piece alone has alleged resemblances to the anthropomorphs.

Like the mid-ribbed sword, the harpoon has backward-pointing barbs and holes at the ends of the barbs. Two varieties of harpoons are known: one cut from a thick sheet, and the other cast in a double mould. Such harpoons could have been used either for killing fish or big game, as depicted in a rock shelter in Mirzapur (*Fig. 14*).

The antennae sword type is confined to the doab zone. Its total length varies from 42 to 75 cm and the antennae projections on the hilt end are more than 10cm in length. I feel that such long antennae would be definite handicaps in using these

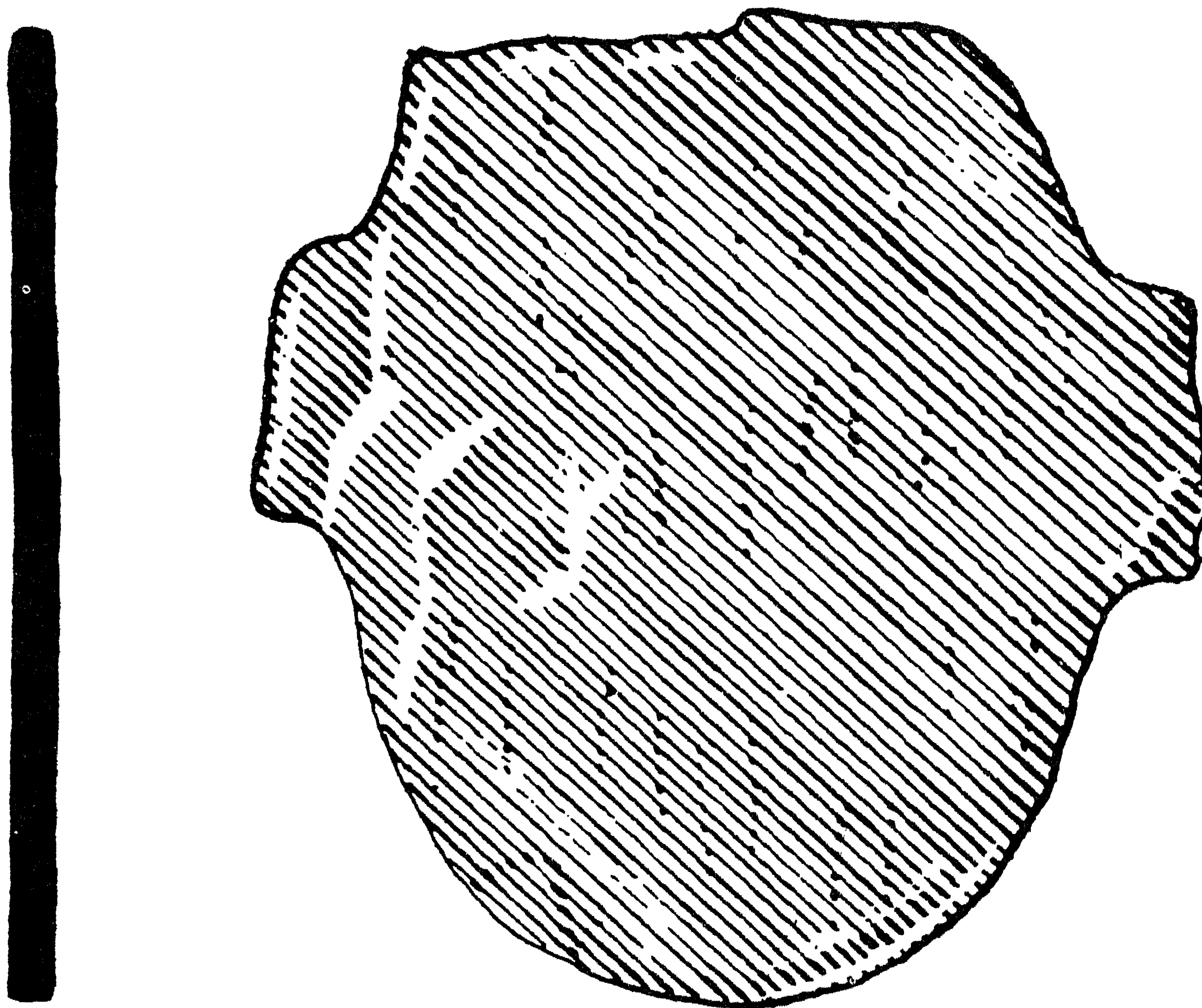


Fig. 13. A flat copper object found at Lothal, a Harappan site in Gujarat, has been compared with the Anthropomorph of rectangular section however shows that it is a different category of object.

artifacts as swords and have proposed that they could have been better used to kill wild game by fixing the swords upright in pits, with the antennae sitting in slits across green logs. If game were stampeded into the pits, the swords would pierce them without buckling, since the green logs (with branches) would serve as shock absorbers. Admittedly, this hypothesis would be difficult to test, except perhaps by examining use marks on a large number of such artifacts.

From the foregoing discussion it is obvious that the essential core of the Copper Hoards consists only of the anthropomorph, the harpoon, the hooked sword, and the antennae sword (*Fig. 12*).

These types are found together for example, at Bisauli, harpoons and anthropomorphs occur together; at Bithur, antennae swords and harpoons are associated; antennae swords and anthropomorphs were found together at Fatehgarh; and the hooked sword was associated with the other three types at Fatehgarh, Sarthauli, Bahadurabad, and Niori (Agrawal 1971).

We would divide the Copper Hoards into two zones: the main doab (Uttar Pradesh) types are specialized tools: the anthropomorph, the antennae sword, the

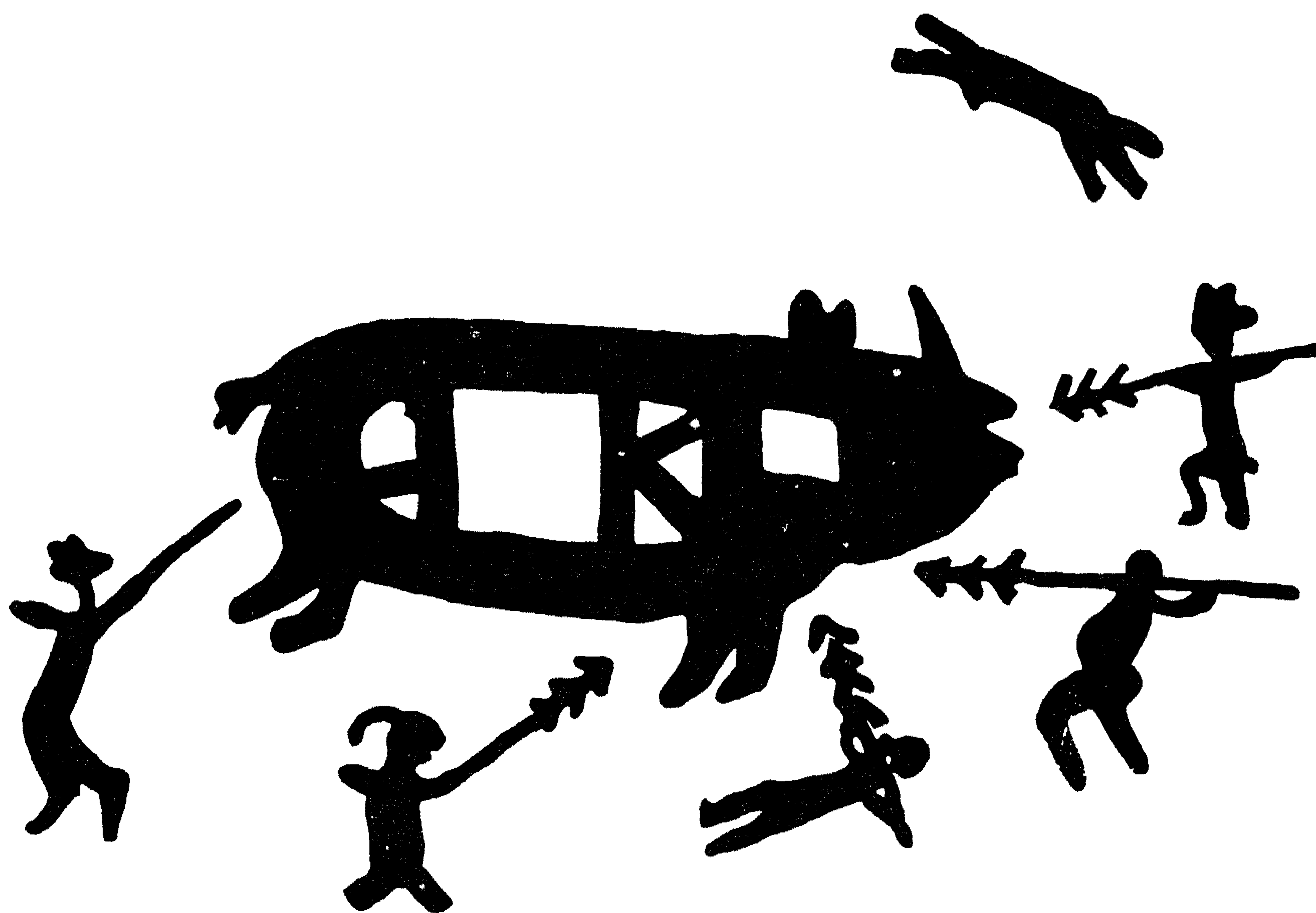


Fig. 14. A rock art illustration from Mirzapur indicating the use of harpoons for big game hunting.

harpoon, and the hooked sword; the main eastern (Bihar) type is the barcelt. Flat and shouldered celts are common to both zones. The barcelt, from sites in copper-rich Bihar, is about 60cm long with a bevelled edge and a thick body. Its sturdiness and length suggests its use as crowbar for digging copper ores, and the use marks on barcells do indicate their use against hard surfaces. The barcelt is the only specialized type in the eastern group; if typology is any clue, the simpler types of Bihar may have preceded the more specialized types of Uttar Pradesh. Except for a reported harpoon from Mitathal, no doab types have been discovered from Haryana or Rajasthan. The *parasu* seems to be a type of this area and has been reported from Mitathal (Suraj Bhan 1975) and Kurada (*Fig. 6*) in Rajasthan (Agrawala 1980).

The distribution of the Copper Hoard types is therefore mainly confined to Uttar Pradesh, Bihar, and Madhya Pradesh. It is beyond doubt that the Copper Hoards have an individuality of their own and were not influenced by either the Harappan or the Chalcolithic cultures. This is further supported by the exclusive arsenic alloying of the Copper Hoards. As regards the authorship of the Copper Hoards, there is considerable controversy. Heine Geldern (1936) identified them with the Aryans, Piggott (1950) with the Harappan refugees; Lal (1951) and Gupta (1963) with the Mundari-speaking Australoid tribes of the primaeval doab; and Sankalia (1974), as usual, finds Western Asiatic affinities for the OCP, and therefore for the Copper Hoards.

Copper Hoards Metal Technology

Because most of the Copper Hoards have been found in caches, they give an impression of abundance of metal. For example, at Gungeria, 424 artifacts with a total weight of more than 400 kg were discovered. Until we find these implements in regular excavations or habitation sites, however, it will be difficult to infer the real abundance of metal in an archaeological context.

An examination of the Copper Hoards artifacts shows that they were made both by hammering and cutting metal sheets, as well as by closed casting. A small percentage of the artifacts (*Fig. 5*) show lead alloying,probably for better fusibility. Metallographic examination of the artifacts indicates slow cooling, cold work, and annealing.

We have few data on the trace impurity pattern of the Copper Hoards, but circumstantial evidence points to the use of Bihar mines. The exclusive occurrence of barcelts in the eastern region may also indicate their use for crowbar-like operations in mining.

More interesting is the evidence of arsenic alloying. Out of the 46 artifacts analyzed by us, 50% show more than 1% arsenic. None of the artifacts, however, has any tin (*Fig. 5*). It is thus obvious that the Copper Hoards technological tradition is different from that of the other cultures. We may recall here that in the earliest phases, both in the Near and Middle East, only arsenic alloying was used (Eaton and Mckerell 1976); tin replaces arsenic only in the third millennium B.C. in Western Asia. At Tepe Yahya, they used arsenic copper ores, which made arsenic alloying easier for them, but there are no significant sources of arsenic in India, although small out-crops are known from Rajasthan, Kashmir, and Bihar. Nal in Pakistan, yielded lollingite ($FeAs_2$). Both of these features, exclusive arsenic alloying and characteristic tool-types, indicate the possibility of the Copper Hoards being an autocthonous, and perhaps the oldest, metallurgical tradition in India.

Before we conclude the discussion on the Copper Hoards, we should take note of some remarkable discoveries made recently in Rajasthan (Agrawala 1979:159-160; Agrawala 1980:89-92). Sixty copper flat celts and some arrowheads were discovered from Ganeshwar in Sikar District of Rajasthan.

Two points deserve notice: first, the arrowheads are of Harappan type; second, the site is only 80km from the rich Khetri mines. Although we cannot technically include them with the Copper Hoards, they do indicate a factory site.

The Khurdi Hoard was reported earlier by Sankalia, but Agrawala (1980:89) reports that the site is actually Kurada, in Nagaur District of Rajasthan. The original hoard consisted of 103 artifacts, but only 10 now remain in the Jodhpur museum. None of the types is typical of the Copper Hoards artifacts; in fact, the channel-spouted bowl has affinities with the Malwa channel-spout and the hatchets with those found at Kalibangan.

Although there is a distinct possibility that some of these sites served as factory centers for the Harappan and Pre-Harappan towns, contacts with the Copper Hoards do not appear likely.

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Mining

R.D. SINGH

The history of mining and use of minerals may be traced from about 4000 B.C. onwards (Sharma and Sinha, 1967, Sharma, 1970). In the Pre-Harappan period evidence of earliest settlements of agricultural communities in the mountainous and desert areas of the country is found. Copper axes and other articles like copper mirrors have been found which were made by hammering, cutting and rolling of the copper metals extracted at about 700-800 C from copper ore probably obtained from Baluchistan.

During the Indus Valley Civilisation period (Harappa- Mohenjodaro culture), highly skilled industries producing on a mass scale bricks, huge water pots and jars, glazed pottery wares, clay bangles flourished. Hematite or manganiferous hematite was used as the colouring material and the tempering material with clay was mica, lime and sand and alkaline silicates probably produced by fusing sand and soda obtained from salt lakes of Rajasthan or rock salt of west Punjab were used for glazing. Light grey coloured gypsum cement made from gypsum, lime and sand was used in some of the buildings of the cities as mortar and plaster for painting walls. Copper and bronze were used in plenty for domestic utensils, axe-heads daggers, knives, arrow-heads, sickles, wires and rods and for bangles, and finger rings, etc. Copper sometimes, contained nickel and might have been extracted from copper ore of Rajasthan, or Baluchistan and Afghanistan.

Gold and Silver were used for jewellery and silver for ornamental vessels. Gold might have been brought from South India and silver might have been obtained from the argentiferous lead ores of Rajasthan or Baluchistan. A large number of minerals, ores and rocks were used in this period. They include quartz and its various varieties, Alabaster and steatite, Cerrusite, Cinnabar, white lead, Lollingite leucopyrites, hematite and slate.

In the post-Harappan period people migrating from Baluchistan, Harappa and Mohenjodaro settled in the gangetic plains of Uttar Preadesh, parts of Bihar, Orissa and Madhya Pradesh. A large number of copper tools belonging to these tribes have been found.

The Vedic period and Ayurvedic period found considerable growth in mining and mineral industry. The *Ṛgveda*, the oldest composition of the Aryans mentions the use of copper, bronze, gold and silver and *Yajurveda* mentions gold, silver, copper, lead, tin and iron. In the Ayurvedic period remarkable developments took place in ancient India.

The earliest and most authentic record of information relating to minerals is found in *Arthaśāstra* by Kauṭilya (popularly known as Cāṇakya). Amongst other things this treatise gives comprehensive account of the properties of ore, minerals and metals with the method of their large scale production and treatment as well as the manufactures of alloys like brass, and also gold and silver alloys with base metals. Properties of gold, silver, copper, lead, tin, iron and mercury have been described.

According to Kauṭilya's *Arthaśāstra*, mining and manufacturing industries were the chief sources of income. The importance of mines is stressed in the statement that "the treasury depends on mines and that the earth is conquered by means of treasury and the army" (Kangle, 1965, p.182). The starting of the new mines and the renewal of old discarded ones was an important state activity in charge of *Ākāradhyakṣa*, the director of mining. The qualifications and duties of the Ākāradhyakṣa are given as follows :- The *Ākaradhyaksa* was to be an expert in *sulbaśāstra* (geology) and *dhātuśāstra* (metallurgy). He was to make a survey of all regions where mineral deposits were likely to be found and start new mines and renovate old ones.[1]

All mines were clearly state property but not all of them were to be worked by the state. It is stated that a mine costly in its working should be leased out for a fixed share of the output *(bhāga)*, or for a fixed rent *(prakraya)* and that only light mines should be worked by the state directly. So far as salt mines were concerned they seem to be all intended to be leased out for a share or on hire. Workers in the state-run mines might be supposed to belong to same category as the workers are on crown lands, namely, *dāsa*, *karmakāra* and *daṇḍapratikartṛ*. In addition those disgruntled with the regime were to be posted in the mines. Men of the officer grade seem to be meant here, since it is stated that their wives and children should be held as hostages, the precaution being intended to prevent the men from going over to the enemy (Kangle, 1965).

It is laid down that the produce of various mines should be turned into articles of use in the respective workshops or factories *(Karmāntas)*. The manufacture of articles from metals other then gold and silver was the concern of *lohādhyakṣa*, who was also in charge of their sale. Another officer the *Khanayādhyakṣa*, was in charge of the manufacture of articles from precious stones and their sale.

The chapter on mining (II.12) of Kauṭilya *Arthaśāstra* is largely devoted to gold and silver ores and deposits of iron ore in a single sutra (II.12.15). While the text devotes two Chapters to the manufacture of gold and silver articles (I.18 and II.14), it merely refers to factories to be started for the manufacture of articles of copper, lead, tin, brass, etc., along with steel and iron (II.12.23) and does not contain even a single *sūtra* concerning the process of manufacturing steel for the articles to be made out of it (Kangle, 1965).

Metallurgy of copper and its alloys (brass and bronze) was highly developed during this period. A remarkable use of brass was made in the constructional work

of an unfinished Vihara (convent) made near Nalanda (Bihar). The Taxila remains (now in Pakistan) consist of ornaments, toilet articles, household vessels, surgical and other instruments of this metal and its alloys. A white alloy of nickel and copper was in use for coinage and jewellery and solders made of tin and its alloy have also been discovered. The famous Chinese traveller Huien Tsang has written about the colossal Statue of Buddha (24 m high) found near Nalanda which is believed to have been constructed during the reign of Purnavaraman (7th century A.D).

Numerous uses of copper in early days in the form of coins of Kushan Kings like Kaniska and his successor and in the following Gupta periods are found. Large number of iron implements and weapons including swords and daggers found during an excavation near Madras are regarded as the products of 4th century B.C. The famous iron pillar bearing an inscription of about 415 A.D. near Delhi by the side of Kutub Minar was constructed in the 4th century A.D.,first erected at Mathura and then removed to its present site at Delhi in or about 1050 A.D. Iron was mined and smelted in India since ancient times and steel making was a highly developed art. Iron does not seem to have been known in the Harappa period but it was known in the Vedic period. Megasthenese mentions iron amongst other metals and fine steel had been used for the manufacture of surgicals instruments for inscribing on stones evidenced by Ashoka's inscriptions on stones. It is believed that Indian steel was exported to Persia and to Western European countries and was known in Europe by the name of 'Wootz' from which the famous Demascus blades were prepared (Sharma and Sinha, 1967). Iron produced in Ancient India was mostly wrought iron and charcoal was the fuel usually employed. In those days steel was produced by a process resembling modern crucible process. The ancient blacksmith extracted iron from local ores e.g., laterite, lateritic soil, ferruginous sandstone or soil. The indigenous iron industry was widespread and prosperous throughout the medieval period as can be seen by the heaps of iron slag strewn throughout the country at numerous places except in the alluvial planes of great rivers.

Description of metals and metallurgy, especially good quality steel and uses of various salt in medicine have been described in the later Caraka and Suśruta Saṃhitās. Detailed description of 64 branches of arts and sciences in Vātsāyana's famous *Kāmasūtra* include knowledge of minerals and mining besides testing for gold and gemstones (Banerjee and Mookherjee, 1984).

India was the world's chief source of gemstone in the ancient and medieval times. Numerous references about this are found in the *Mahābhārata* and several ancient works dealing with gems exist. India was only supplier of diamonds to the world before the discovery of diamonds in Brazil in the year 1725. Although there is no direct reference to the use of coal in ancient times archaeological evidence suggests that coal was used in India in ancient times. Also, the word *'Aṅgāra'* (derived from Agni, the vedic god) meaning fuel, occurs in several places in the Vedic Literature. The *Śukla Yajurveda Samhitā* (eleventh chapter 19 kāṇḍa,), writes, "O my horse: test earth with your feet and search for fire, touch the soil and tell us which place we shall dig".[2] Digging the earth for fire here many mean mining for coal.

It may not be entirely fanciful to presume that digging the earth for fire meant mining for coal. It is evident from the ruins of smithies, furnaces and slag heaps

very close to the coal regions in eastern part of the country that coal was commercially used much before the sixteenth century.

"Some historians and other experts believe that the evidence of finished high grade copper and steel alloys found in India from 4th century B.C. onwards throughout the muslim period bears evidence of metallurgical processes undertaken with the help of coal and coke especially in the eastern coal bearing region of the country" (Banerjee and Mookherjee, 1984).

Mining of Some Important Minerals

From the records of foreign travellers and historians like Megasthenes, Pliny, Fa Hien, Huen Tsang (7th century), Al Bīrūnī (11th century), Tavernier (1665-69) information on mining and trade of various metals and gemstones, use of steel and other alloys in India in the various ages is found. Techniques of mining copper, lead and zinc, gold and diamond, etc was well developed and the process of development continued till the beginning of Medieval period.

Copper Mining

Old workings of copper mining of ancient times are found in various parts of the country e.g. Singhbhum copper belt, Bihar, Khetri Area, Rajasthan and Ambaji, Kumbaria in Gujarat (*Fig.1*).

Mining for copper is known in the Singhbhum copper belt since about 600 B.C. (Sarkar, 1987). Numerous ancient pits, slag heaps scattered all along the belt bear testimony to the enterprise of the miners of the past. In the western part of the country in Rajasthan copper mining was done at Khetri during the Mauryan period around circa 300 B.C. The first recorded mention of copper mining is found in the *Āin I Ākbarī* (Ain II p.194) written during the reign of Akbar by Sheikh Abul Fazal in 1590 A.D.

Besides Khetri, in western part of the country copper mining was done in ancient times at Ambaji, Kumbaria in Gujarat and at Deri in Rajasthan. Extensive old workings for copper, lead and zinc ores, and for by product gold and silver extend over an area of 2 sq km to the north and north west of Ambaji village in Danta Taluk of Banaskantha district, Gujarat, Another small area of ancient working for the above metal spread over an area of 0.2 sq. Km is located at Deri on Abu Road Taluk of Sirohi district, Rajasthan. Also ancient workings are found at Watera, Pipla, Golia, Basanthgarh for copper (along with zinc) at Basanthgarh north of Ambaji in Sirohi district of Rajasthan between Abu Road and Sirohi. ^{14}C radio carbon dating of the wood samples found in the old workings and of charcoal in slag dumps indicate that the earliest mining activity falls in the second Century B.C. The other dates are in 1100, 1200 and 1500 A.D (Shekhar, 1983)

Literary evidences also of mining of copper at Ambaji and probably at Deri come from Jain literature of 11th century and onwards. Evidence of foreign travellers who visited the country between circa 200 B.C. and 150 A.D. attest to abundance of copper in India and their export to West Asian countries through the port of Barygeza (present day Broach in Gujarat).

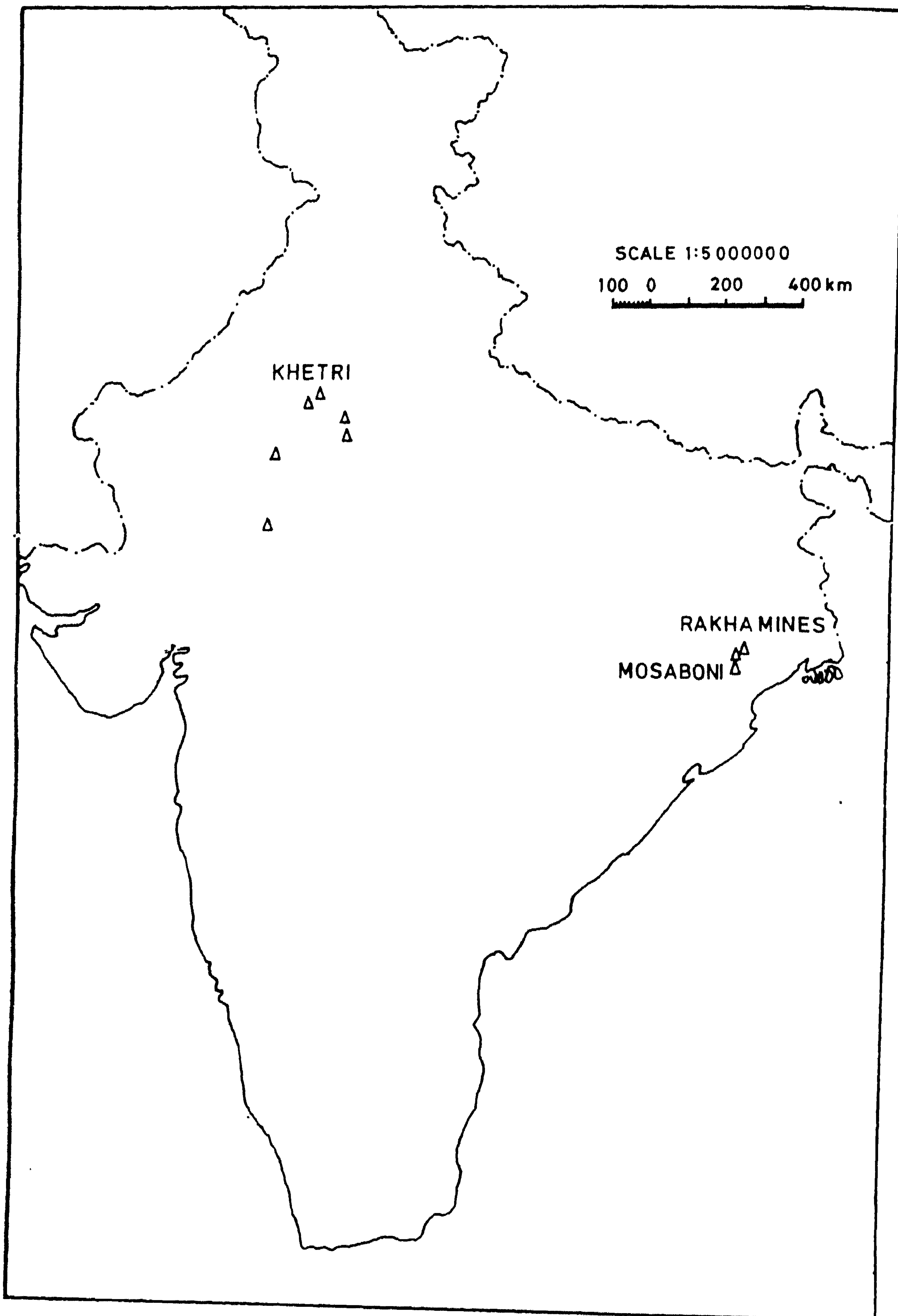


Fig.1. Sites of ancient copper mines in India

Singhbhum Copper Belt

In the long past a race of ancient people mined and smelted copper ores in the copper belt of Singhbhum some 2000 years.ago (Dunn, 1937) which was the centre of industry and of comparatively high civilization. Names of localities like *Tama Pāhār* near *Rākhā* mines, and village called *Tamajuri* (specks of copper) point to ancient copper industry.

Signs of original occupation by Saraks or Lay Jains exist who are said to be responsible for copper mining in Singhbum copper belt. Ball (1869 p.172) drew attention to many signs of original occupation of the district by Saraks or Lay Jains. There are many tanks and ruins which the villagers now refer to as of Sarak origin. He came to the conclusion that it was these Saraks who were responsible for the working of the mines. According to Colonel Dalton the Jain were driven out of Singhbhum more than 2000 years ago (Dalton, 1866 p. 164). The latest period of working in Singhbhum copper belt was probably between the third and sixth century as suggested by some old copper coins of the later Kushan type found at Rakha mines by Mr. Shoyer.

Local legends go that the tower with three terraces found just South of Rakha Mines, which is the centre and most important part of the copper belt between Rajdah and Badia, is part of a fort situated on top of the ancient mines. This fort served as a watch-tower for the Rajah who was working the mines. Around the tower at least three terraces have been cut in the laterite. One of these terraces is 8 ft (2.4 m) wide and 3 to 4 ft (0.9 to 1.2 m) high. It is said locally that there were originally three entrances by tunnels, in the north, south and the east of the hill into a centre below the tower (Dunn, 1937).

Copper is recorded to have been transported down the Subarnarekha river to Piple situated at its mouth which had copper as one of its chief exports. An old road used by the Chinese is said to have existed in Emperor Ashok's time from the Subarnarekha river east of Ghatsila to Tamluk on the Rupnarain river and the mining of this area has been credited to Chinese.

In ancient times workings descended up to ground water level. Almost entire copper ore was extracted except in pillars for support of walls (which indicates considerable skills, patience and large manual labour). Timbering was not done except for holding in place broken schists separated by greasy partings. Dunn (1937) writes "One of the stopes at the south end of No 1 level, Mosaboni broke through into an ancient working, about 6o feet (vertically) from surface. The working is about 4 feet wide across the lode but extended for only a short distance along it, as this point was, of course, the bottom of ancient workings. After breaking through, old rotten timber was found, fragments 5 to 6 inches in diameter. Timbering was not a usual practice of ancients, pillars being left to hold up the hanging wall. At this place the hangingwall was very broken, slabs of schists being separated by greasy partings and timber was probably used to hold up such loose slabs".

Occasionally tools. and utensils of soapstone and pottery have been found in workings..Stone implements of ore-grinding have been found quite close to mines and are relics from an older age. The great extent of workings indicates the work of several centuries with the type of stone tools used for dealing with and excavating

the hard rock encountered in many of these lodes and it is quite likely that the working was intermittent due to unstable working nature of those times.

The workings are approached by adits driven in the hill side. The adits are 3ft (1.8 m) × 3ft to 8ft (1.8 to 2.6m) × 4ft (1.2m) in dimensions. The ore worked is sulphide but sometimes oxide have been worked which have extended down into sulphides.

The stope width was 4 ft (1.2 m) and when timbering was done the timbers were 5-6 inches (12.70-15.24 cm) in diameter. Similar type of primitive mining was done by Nepalese miners in the nineteenth century as reported by Bose. (Bose, P.N, 1891).

These miners extracted the vein stone by chisel and hammer to a maximum depth of 60ft (18m) which is the water level. The ore extracted was copper pyrites with copper contents of 20.31%. Drives were 4ft (1.2m) high × 3ft (1.8 m) wide. Chips of bamboo were used as lights. For grinding, the ore was placed on a flat rock, then broken and ground by a small flat stone which was shaped in such a way as to fit the hand comfortably.

The smelting was done with charcoal. Ancient furnaces in the vicinity of slag heaps show that these were always made of clay with clay tuyeres. The slag heaps cover a long area between Rakha mines and Roam and have variable depths up to 1.8 m. A typical analysis of slag near Mosaboni contains only 0.26% copper which is as good as can be obtained from modern smelters.

Khetri Copper Area

Lay Jains are believed to be responsible for mining copper in Rajasthan many centuries ago. Evidence of same type of work as in Rakha mines are found in a number of workings now known as Khetri copper mines in Rajasthan which occur in a long range of quartzite hills in Rajasthan. Along a length of 15 miles (24 km) numerous openings are met on the crest of these hills connected to underground excavations which in some cases open out into considerable underground excavations worked out areas. These in some cases are a few hundred feet long and up to 40 ft (12.19 m) wide. Tunnels fan out from these open excavations following rich lodes of ore and workings have reached to a depth of 500 ft (152.40 m) below the hill top. The underground galleries or tunnels are 5 ft × 4ft (1.5 m × 1.2m) or 4ft × 3ft (1.2 m × 0.91 m) and have their sides notched or cut so as to allow ingress and engress without the use of ladders. In order to get fresh air the ancients drove galleries to puncture the hill sides at several places and dilute the vitiated atmosphere. The age of these mines is reckoned to be Chalcolithic Age, (Bose, 1968).

The ore was dislodged at the face by fire-setting and quenching it with water and thereafter it was extracted with chisel and hammer manually. The broken ore was transported out of the mine in baskets carried over the heads of a series of labourers.

Brooke and Boileau have given excellent accounts of mining and smelting of copper in the Khetri area in their papers which give an insight into the mining techniques employed in the ancient days and are summarised below:

As said earlier the ore was cracked at the face by fire- setting. For fire-setting at the face some 150-200 maunds (5.6- 7.5 tonnes) of fire wood was stacked in a compact manner which was set on fire, and immediately thereafter miners went out of the mine quickly lest they should be smothered in the galleries and meet with fatal accidents. On approximately the third day of fire-setting the miners went inside the mine to find that the rock/orebody at the face was cracked and split into huge masses by the violence of intense heat and when the workings were sufficiently cooled, they proceeded with the work of extracting the ore. Each face worker was provided with a lamp, a 'gad' or mining chisel and a small basket. The lamp placed upon workmen's head not only provided illumination for the execution of his work but also enabled him by watching the glittering particles of metal to detach only such portions of the ore as might promise him the best remuneration for his labour. While at work the miner seated himself upon his heels with the lamp upon his head, the hammer in his right hand and the 'gad' in his left hand and the small basket upon his knee in which he received all the fragments of ore that were struck off by the chisel.

"The bamboo baskets of ore were passed along a chain of persons, usually 4 to 12 in number who set upon their haunches in the galleries or stood on the niches cut in the shafts, when the whole reached the foremost man, they moved upwards and again ranged themselves and this was continued until the mouth of the mine was reached."

The confined posture, the lack of fresh air and the excessive heat in which the labourers worked took heavy toll of human lives which were usually extinguished at the early age of 30-40 years.

The mines were worked only during eight months in each year beginning from October and the workings were suspended during the rains. Also the miners were obliged to work during the nights discontinuing their work early in the day for the excessive heat might otherwise be fatal. When the day work was completed the miners returned home with the proceeds of their labour which was collected at a public *'cabūtra'* near the smelting furnace.

The ore was finely powdered using *'ghuns'* or heavy hammers weighing 32 to 34 pounds (14.51-15.42 kg) each. The ore had to undergo hammering three times before it was fine enough for roasting process. The powdered ore was next mixed with cow-dung and made into rolls about 4 inch (10.16 cm) long which was dried first in the sun and then roasted in the open air in a fire of cow-dung cake. The ore was then ready for smelting.

For smelting ore the furnaces were built locally. The furnace was cemented with clay and the nozzles of the bellows were built up in it. The nozzles were earthen tubes which were thickest at the furnace end and at the top of the thick part there was a small air hole usually closed with a piece of wet rag but opened now and then to clear the tubes. The other end of the tube was fixed to the bellow. The bellow valve was formed by two sticks at the mouth, which were opened when the bag was raised for the admission of the air and closed when the bellows were pressed down. The upper part of the furnace was built with rings of fire-clay about 10 inch (25.4 cm) deep. The bellows were worked on three sides whilst the fourth side was the

opening to the furnace, in which a plate of fireclay was placed, at the lower part of which was a hole for stirring the molten metal and to allow it to flow out.

After the furnace was lit, the roasted ore was gradually introduced alternatively with charcoal and a flux, called 'reet', the refuse from old iron furnaces.

In conclusion it will be pertinent to say that copper mining in ancient times was done in almost all the areas where present day mining is being done. The ancients had the skill to explore for the ore deposit and mine only such portions which would be remunerative. Mining was done by firesetting and quenching to initiate cracks in the orebody followed by extraction of ore with chisel and hammer. Transport of broken ore was done in baskets carried over the head of labourers. Ventilation at the working face was not systematically organised; for fresh air often the underground tunnels were connected to the surface by shafts. The mining depth was limited up to the water table.

Gold Mining

Mention of gold in India has been made in the *Ṛgveda*, the *Sūtras*, the *Purāṇas*, in the *Mahābhārata* and *Rāmāyaṇa*, in the Hebrew and Roman Scriptures and in Greek and Roman literatures. The Harappan culture of 3rd and 5th millennium B.C. testifies to the world the early activity in Kolar Goldfields.

From the very earliest times gold has been produced in India by the inhabitants of the country either by mining the outcrops of gold bearing quartz veins or by washing sands for sparsely disseminated alluvial gold.

In Raichur district, names of villages starting with 'Honnu' and 'Chinna' (which means gold in Old Kanarese) suggest gold mining. At Maski an ancient gold metallurgical plant was discovered barely 100 yards away from a cave containing Ashokan inscription. It is more or less certain that Phoenician traders carried away the gold from India in olden days.

There appears to be little doubt that at some unknown period in the mists of Indian history (perhaps as far back as 2000 years ago) a race of people highly skilled in mining and metallurgy explored and prospected all the auriferous areas in South India. Ancient workings are so widespread that no reef carrying economic values appears to have escaped the attention of these early prospectors.

The actual date when gold mining was started in India is not known. Hutti mine, which is probably one of the most ancient mines in the world dates back to the pre-Ashokan period. As per carbon dating done by Rafter of Australia in the year 1955, the age of the two samples of timber found in the old workings was estimated to be 1900 year old.

It is noteworthy that practically all the working mines in India have been established only on deposits indicated by the existence of ancient workings. One of the foremost among them are K.G.F.. mines. The other mines are Hutti gold mine, Kudrikonda (South West of Hannnali), Jalagargundi North of Chitaladurg, Ajjanhalli and Bellora Mines (Karnataka State). North Anantpur and Jibutil mines (Andhra Pradesh), the Dharwar reef mine, Wynad district mines (Maharastra). *Fig.2* shows the locations where ancient workings of gold have been found.

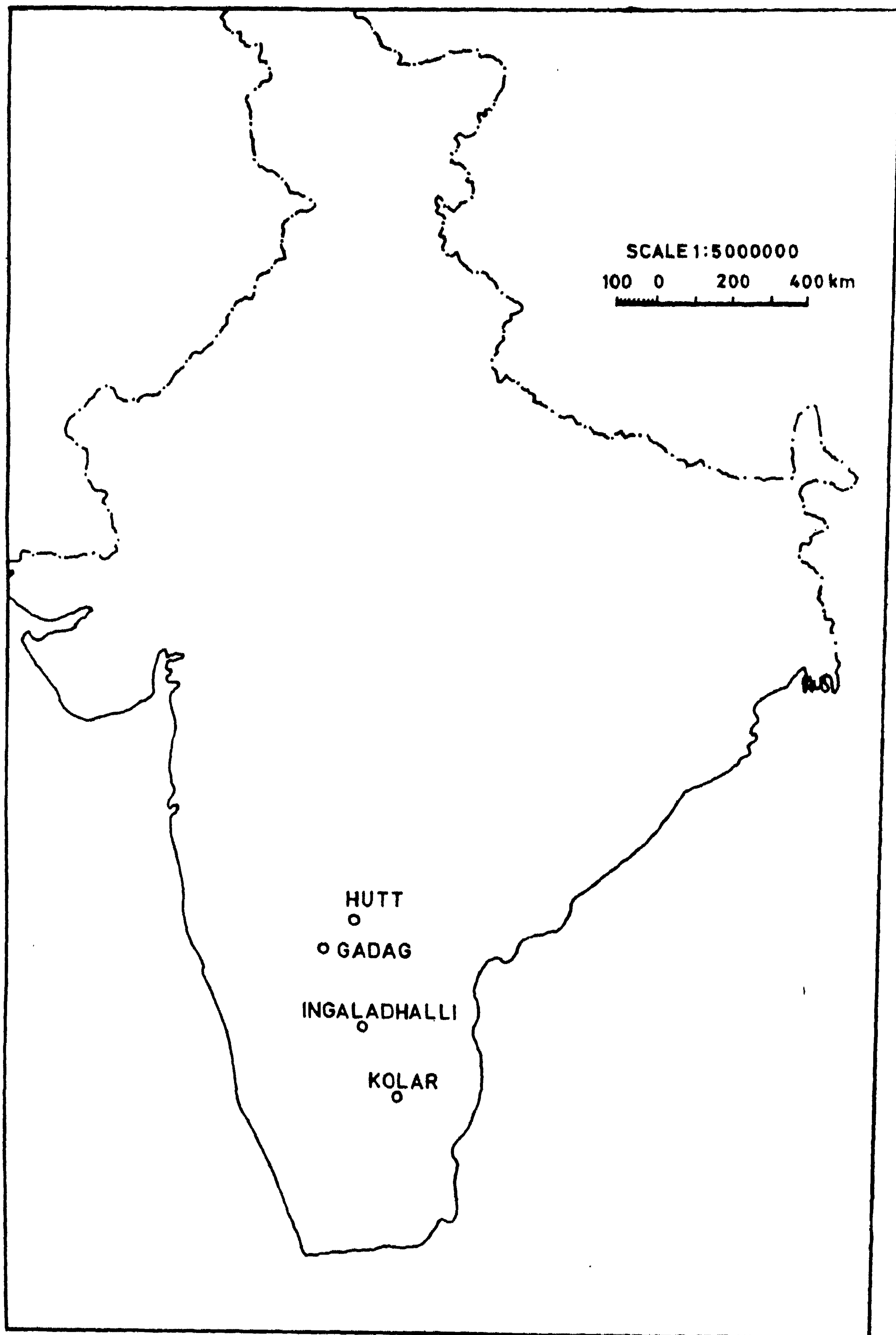


Fig.2. Sites of ancient gold mines in India

Maclaren (1905) and Munn (1934, 1936) in their articles have given descriptions of the ancient gold mines which have been summarised

(i) At Hutti, the old workings reached a depth of 640 feet (195.07 m) a depth unparalleled by another truly ancient working yet discovered in any part of the world. The difficulty of working must have been accentuated by the steepness of the reef and by the hardness of the rock, every inch of which was doubtless broken by the laborious method of "fire setting", heating the rock with fire and dashing water over the heated surface. Pieces of charred wood used for this purpose are still to be found in the old workings.

Beyond this evidence, that of a few vertical groovings on a shoulder of the hard footwall at Hutti, and that of a couple of tools found in the old workings at the same place, there remains no trace of the methods used in the extraction of quartz. The groovings are undoubtedly the results of the long continued attrition of haulage ropes. A scraper like tool was also found and similar tool was found at Oorgaum mine at Kolar (Smith, 1889). A chain of men handled from one to another vessel filled with water. A vertical shaft at Kabulayatkatti indicates that the ancients were not ignorant of some form of windless 'whip' or 'whim'.

At Wandalli some of the old workings were 100-150 ft (30.48- 45.72 m) long, 20 ft (6.096) wide and as much as 15 ft (4.5 72 m) deep. The old workings were reached at a depth of 380 ft (115.82 m) in No 3 shift.

Smith (1931) writes in a report to His Exalted Highness, the Nizam's Government.

"I quote The Mining Journal —— that the ancient miners had gone down over 400 ft (121.92 m) vertically in some of the hardest rock known to modern mining".

"The ancient miners took out all the pay ore at Wandalli down to 400 ft (121.92 m) level".

(ii) At Topaldoddi mine the ancients mined on very rich patches of good quartz without any continuity. There are large number of small pits honey-combed over this zone.

(iii) At Kadoni the ancients have taken away practically every thing down to 140 ft (42.67 m). There is a large old working 15 ft (4.57 m) deep and upwards of 60 ft (18.28 m) in diameter.

(iv) In the South Maski field two chief lines of old workings exist, namely: (1) those in Maski village lands and (2) a very big working 409 feet (124.66m) long within the lands of Udbal. A map (*Fig.3*) prepared by Aubery shows a line of 13 old workings at Maski where one of the biggest old workings was 117 ft (35.66m) deep.

At Chik Honkuni at the southern end of the inlier there are six adjacent old workings in all about 500 ft (152.4 m) in length.

At the bottom of old workings at Hutti and other places in South India, about 10 ft (3.04 m) of broken 'chatties' (clay pots) have been found which were used for bailing water.

The old workings have also been found to have been filled up deliberately handpacked with large boulders and rock pieces and debris perhaps to conceal

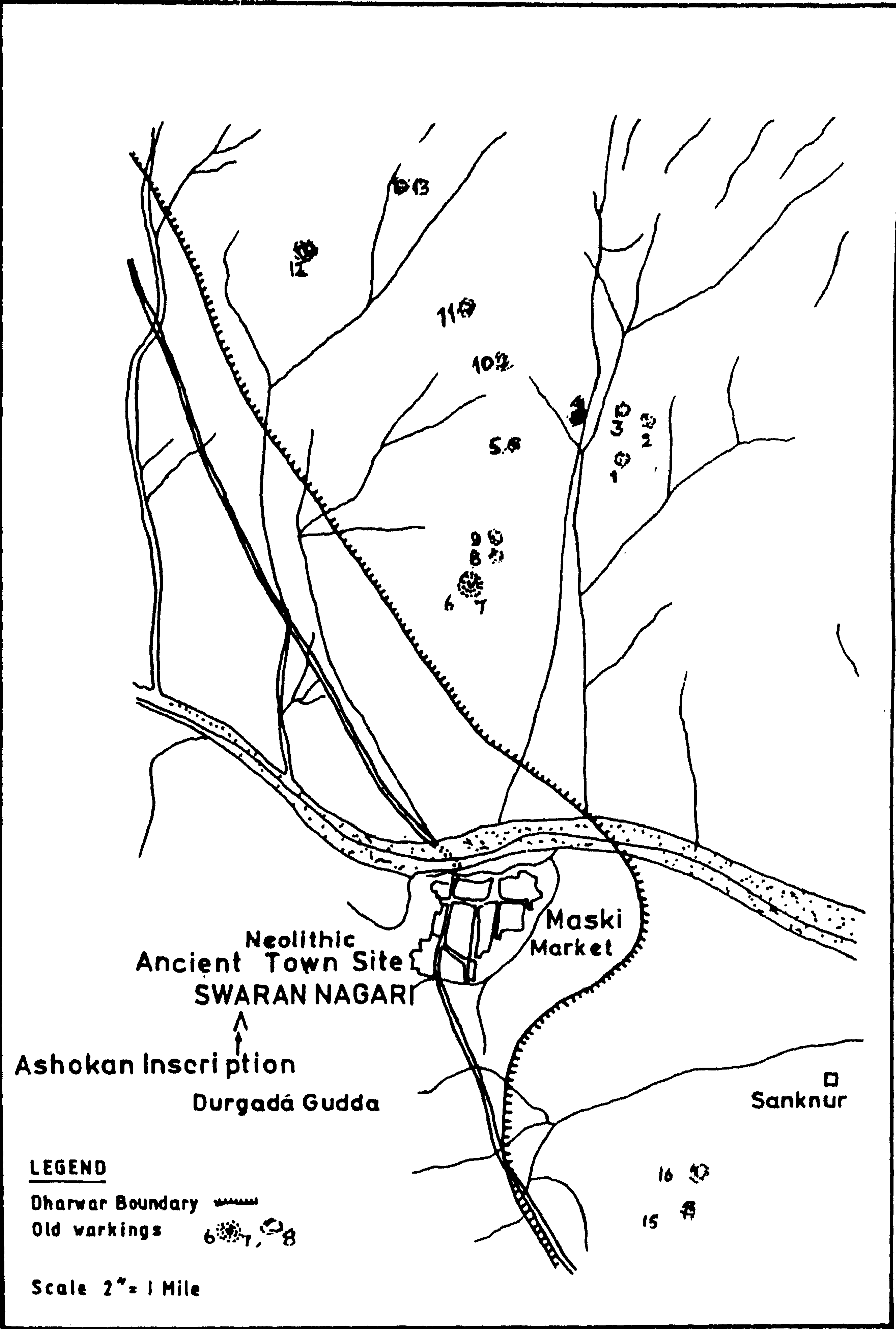


Fig.3. Map showing old workings at Maski (after Munn)

mining work from the invaders or prevent in-flow of water and collapse of workings.

In 1980 an old gold mine called Mangalur Gold Mine in Shorapur Taluk of Gulbarga district, Karnataka, was opened which was closed before the world War I The reclamation work revealed that the ancient people used wooden trolleys chassis (*Fig.4*) for tramming purpose and wooden rings (*Fig.5*) were used as turn table (Munn, 1934).

There is clear evidence all over South India that wherever reefs, veins, or stringers of quartz occurred carrying anything over 2 to 3 dwts of gold to the ton, they did not escape the attention of early prospectors. They were systematically explored, prospected and mined. Mostly the depth to which mining was carried out was limited by water. Fire-setting was the means employed for extracting the ore and in the bottom of the old workings at Hutti as well as others wood ash and charcoal were found. The only suggestion as to the tools employed comes from a gouge like iron implement found at Hutti which apparently seems to have been fitted on to a wooden hat to make a pointed instrument. Windlasses and ropes were

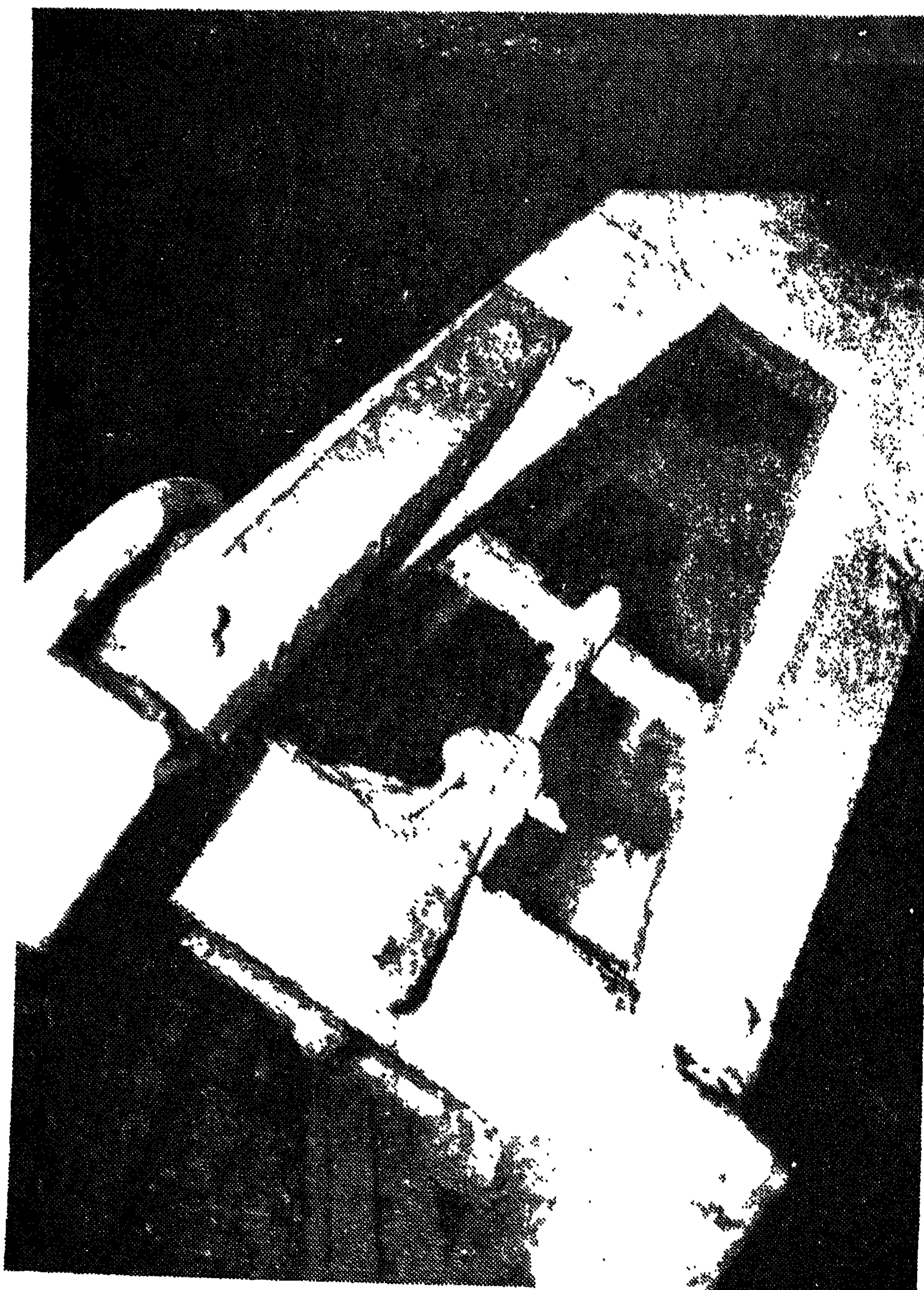


Fig.4. Wooden trolley used by ancients for tramming



Fig.5. Wooden rings used by ancients as turn table

employed; one was unearthed at Hutti where the face of the rock was found to have been rubbed into grooves by the wear of the rope (Munn, 1934).

"Timbering of working places was understood and balks of babul (accasia arabica) were discovered. When the old workings at Hutti were first pierced at about 500 ft (152.4 m) an explosion of gas occurred, probably due to sudden release of pressure on the accumulated gases by old rotting timber.

Water was the main problem that seems to have finally limited the mining operation in depth. A small spring in Hutti mine at 640 ft (195.07 m) brought their efforts to a close and at that level the presence of about 10 ft (3.04 m) of broken chatties (clay pots) was a clear evidence of how the ancients attempted to deal with this obstacle.

Many saucer like depressions in the hard trappoid rock and large granite crushing stones mullackers some over a ton in weight scattered all over the Dharwar rocks, together with small pounding holes for initial crushing of the ore, give evidence of

the metallurgical process prior to final panning. A large battery of these are to be found at Wandalli (Munn, 1934).

The process of the extraction of the gold after the quartz had reached the surface are quite clear. The quartz was broken to about the size of a walnut in small cup shaped depressions in an adjacent dyke and was then introduced beneath great granite boulders which were rocked to and fro, crushing the quartz to powder by their own weight. The bottom rock on which crushing took place was preferably a diabase dyke, but where these were not available as at Wandalli, the harder Schist bands were used. The upper crushing stones were of intrusive diabase or of granite. Probably the boulders were transported to Wandalli from Yelagatti where they were formed by nature from porphyritic granite. Some of those boulders weighed more than 18 cwts. Crushing stones are occasionally found at considerable distances from quartz veins, and it would seem that it was only during the rains that crushing was effected near the workings where these were located at some distance from a water course.

The final process of washing the gold was done in shallow wooden trays (Maclaren, 1905).

The extraction of fine gold was carried out by adding mercury to a mixture of black sand and gold ore. They would rub the black sand mixture by adding a little common salt. In a little time the gold and mercury would form an amalgam and adding a little water to the mixture and agitating the dish, the particles of amalgam would come together and form a lump and black sand would be washed off. This lump of amalgam was rolled in a damp rag and after the superfluous mercury was squeezed off the rag, it was burned in a fire and a button of gold recovered. If the gold was found alloyed with silver or other base metals, it was hammered out between the two stones into a sheet. This sheet was coated with salt and with a little nitre (if copper was thought to be present). The plate was then laid between two layers of cow-dung and burned, the ash of the dung acted as a cupel and absorbed the base metals and left the pure gold (Bharat Gold Mines Ltd, notes, 1979).

Judged by the standards then prevailing gold mining in ancient India was a highly developed industry. As regards the technique of mining, the method as common with hard rock mining for other metals was fire-setting and quenching with water to create a system of cracks in the rock enabling the extraction of ore with some scraper like tool. The excavations were supported by timber and pillars of ore were left to support the ground right from the top and the method of mining resulted in a series of open cuts as the top (Bose, 1968).

Evidence of the use of earthen pitchers for bailing water and use of wooden trolleys for transport and windlass for hoisting have been found.

Ventilation was not systematic. For fresh air the ancients depended entirely on natural ventilation.

Lead, Zinc and Silver Mining

Lead, zinc and silver mining has been done in India from ancient times. Table 1 gives the radio-carbon dates in years before present (b.p.) for remains found associated with mining and smelting at Rajpura Dariba, Rampura-Agucha, Zawar

Table 1— Radio-carbon dates in years (before the present) for remains found associated with ancient mining and smelting of lead-zinc- Silver.

(After Paliwal, Gurjar and Craddock 1986)

Sample Description	Date (bp) identification
DARIBA	
East Lode 4m to 5m depth, wood sample	2215 ± 85 Acacia sp.
South Lode 100 m depth, timber support	3040 ± 150 Aogeissus sp.
East lode 100 m, timber support	2365 ± 85 Bamboo
South Lode 100 m depth rope	2100 ± 280 _____
AGUCHA	
Wood support from 30 m depthM 2240 ± 60 Terminalia sp	2240 ± 280 _____
ZAWAR	
Balaria mine 10 west stope 1st level 415 MRL timber	170 ± 50 Terminalia sp.
Mochia Mine	2360 ± 50 Terminalia sp.
Zawar Mala mine	2410 ± 100 _____
Timber from Launder	1920 ± 50 _____
Timber from Scaffold	2120 ± 60 _____
Zinc smelting site charcoal	230 ± 60 Artocarpus sp.
Base of debris heap in old Zawar site charcoal	80 ± 60 _____
INGALDHAL, Karnataka	
Copper mine 30 m to 40 m depth, wood	1810 ± 35

(Rajasthan) and Ingaldhal (Karnataka). Radio carbon dating of mine timber and charcoal shows that large scale mining took place between 3000 years (late Chalcolithic - early Iron Age in India) and 1800 years ago to a maximum depth of 254m for lead, silver and zinc with a further phase for zinc at Zawar and lead and copper at Rajpura- Dariba from the 13th century to late 18th century. (Paliwal, Gurjar, Craddock, 1986). Investigations of the mines at Zawar show that about 2200 years ago sphalerite production took place at Zawar though it would have then been roasted to oxide and combined with copper to make brass by the cementation process rather than via the metal (Willies, 1987).

Fig.6 shows the locations where evidences of large scale ancient mining of lead, zinc and silver have been discovered and have been described by many authors including Willies (1984, 1987), Paliwal, Gurjar and Craddock (1986), Craddock, Freestone, Gujrar, Hegde and Sonawane (1985). Also Hindustan Zinc Limited in

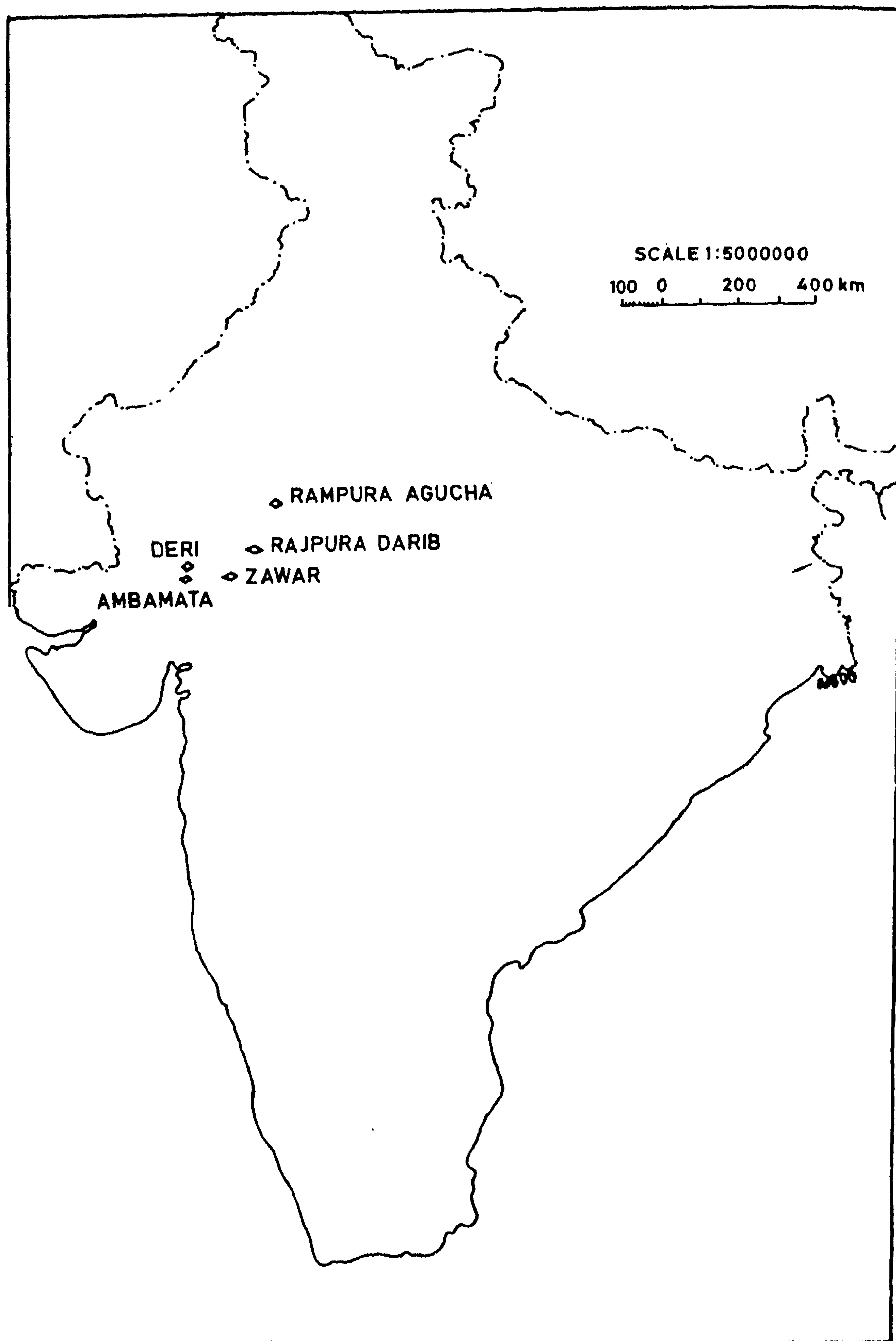


Fig.6. Sites of ancient Lead, Zinc and Silver mines

their leaflets and publication have given information on the history of mining and smelting at Zawar, Rajpura-Dariba, Rampura-Agucha,etc. Radio carbon dating of the remains of wooden stairways, haulage scaffolds, stagings and other artefacts retrieved from the ancient mines indicate that lead-zinc mining existed as far back as 500 B.C.

The rocks of Zawar area constitute a part of the Precambrian Aravali system and include and assemblage of low grade metamorphosed calcareous, arnaceous and agrillaceous sediments. Dolomite which is the principal host for lead and zinc is sharply inclined into steep ridges above the valley bottom. All the dolomite ridges are extensively honey-combed with ancient workings which follow the plunge of the orebody downward from the outcrop for several hundred metres with no access from the valley side.

The remains of wooden stairways, incline haulage scaffolds, staging and dainage leats survive in the Zawarmala mine. Samples taken here for carbon-14 dating from a haulage scaffold and a drainage leat reveal that these are 2000 years old (*Table 1*).

At Rajpura-Dariba ancient mines in the form of vertical shafts, inclines, underground galleries, underground open stopes and open trenches are found scattered all along the strike of lead-zinc orebody. Radio-carbon of pieces of mine timber, rope and bamboo basket from the ancient workings here indicates that these mines were in production approximately 3000 years ago. A piece of lead metal recovered from the slag dump was found to contain 97.5% lead and 150 ppm silver indicating thereby that the smelting technology was advanced.

At Rampura-Agucha the ancient mine workings are preferentially located at the northern limit and the hangingwall of the deposit. A piece of wood from the mine workings has been carbon-dated at 2240 years before present (b.p.). Analysis of some of the slag samples suggests that zinc or zinc oxide was being deliberately produced here 2000 years ago.

In his paper entitled 'Ancient Zinc-Lead-Silver mining in Rajasthan, India', Willies (1987) has given detailed description of ancient mines at Zawar, Rajpura-Dariba and Rampura-Agucha which is summarised below:

Zawar Zinc Mines

Ancient mines at Zawar are found both opencast and underground. A rough and conservative calculation suggests that perhaps 250000 tonnes of zinc concentrates were extracted from some 2.5 million tonnes of ore in the total mined area, before modern mining commenced. *Fig.7* shows a plan of the old workings at Zawarmala mine and *Fig 8* presents a view of an ancient stope (Willies, 1987).

Ancient workings are found at the outcrops on the ridge of Zawarmala, some 120 m deep below the surface. At the surface mine workings occur at intervals of 50 m or so on either side of narrow valley formed by denudation of an anticline at the top of the ridge. Most are very small openings directly into the host beds, inclined at up to 40^0. Only a few shafts are visible at the surface. At one of the mines, known as Pratap khan the entry to the mine is from a small quarry, obviously the result of opencast working of ore. Excavations have been done by 'gads' (pointed chisels) and traces of 'gad' marks are common in the quarry, and in the

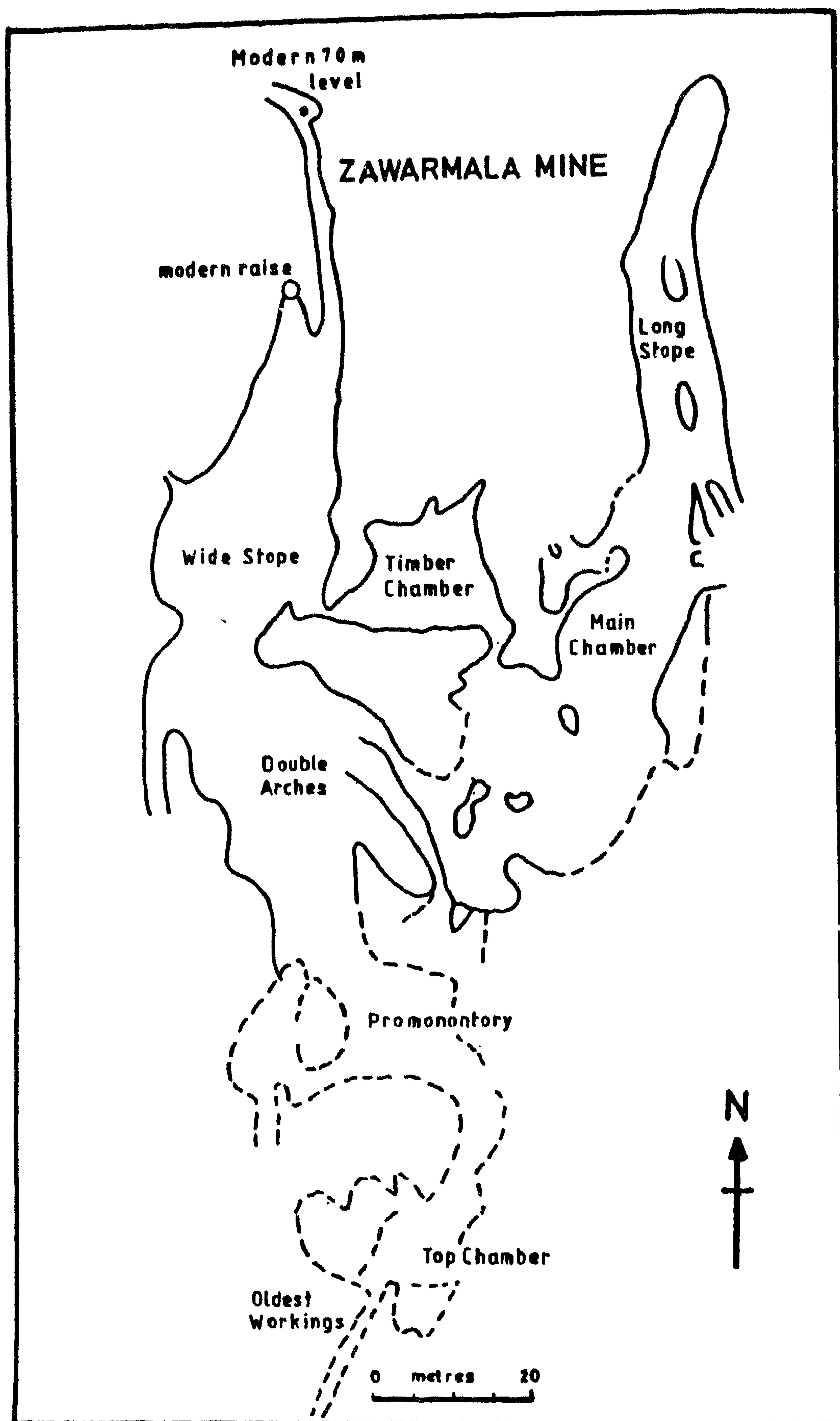


Fig.7. Plan of old workings at Zawar Mala



Fig.8. A view of an ancient stope at Zawar

mine. The most notable feature of the mine is the development of path ways and steps.

Based on his observation Willies (1987) opines that it is evident that there are atleast two stages of mining: the main section with the pathway is 10-20 m wide x 2 m high which seems to cut through older much smaller ramification of tunnels, small chambers, and small climbing shafts. Most of the works seems to have been done by hammer and 'gad', exploiting weaknesses in the partially sheared dolomite. There is evidence of fire-setting near the entrance in the hollows in the roof, and at the bottom of workings. Waste debris is held back by carefully built stone walls, mortared with clay.

Deep underground extensive workings exist at Zawarmala which can be followed up dip to very close to surface. The highest, perhaps, the oldest workings

are formed of small arched chambers, some 3 m across and approximately 3 m high. Access is very constricted, at times one has to crawl to pass through it. It is blocked entirely at the upper end. The method of excavation seems to have combined fire-setting and hammer 'gad' work, with possibly the use of small picks to extract ore in narrow places. Another old and highest working is some 30 m long and 5 to 8 m high and wide. There are characteristic fire hollows in the walls, and rounded roof and pillars of firesetting. The sloping floor has been worked up dip by means of 'benching' using fire holes on three benches following each other. Lower still in the workings, the mine has been worked almost entirely by fire setting with very little 'gad' work evident. The pillars are 5 to 10 m apart and upto 5 m high, often infilled partially and sometimes wholly with dumped waste. Through the area a clear and well made path has been made, with stone and wood steps where it is steep. A sample of wood from the area has given the age 2149 years before present.

At another place the area has double arching, one set above the other. Evidently the upper arches were formed in the original advance-dip, the lower by reworking towards the up-dip.

Another stope 20-30 m across about 2 m high on average, with only occasional pillars is found. In this stope fireset holes are found both lateral, and in the floor and also in the roof. Timber props have been used both to hold up roof flakes and to stablise waste on the slope. Shallow trenches have been dug to convey water inflows to the path, and there are wooden launders for a similar purpose. One launder measured 5 m long u-section 30 x 30 cm. A radio carbon age of one launder gives 1920 years before present.

At the bottom of 'wide stope', the 'finger-stope' has been developed. These are fireset inclines, about 3 m diameter, and sometimes 5 m or more of characteristic rounded section and driven down-dip at 30-40 degrees inclination. They follow richer shoots of ore. The substantial crossection presumably allowed cold air to flow at the floor and hot air to return at the roof level. No brattice was used. This decline was worked in two benches. Samples from a 'timber chamber' yielded an age of 2120 years.

Another big chamber 30 m across and perhaps 20 m high was developed on the dip. It is likely that work continued using firesetting to widen the stope after the limiting depth was reached, no doubt coinciding with the removal of pillars between the two finger stopes. Burnt wood residues suggest an age of 2180 years before present.

There are large amounts of burnt wood fragments of small sticks 50 cm or more long and 5 or 6 cm diameter, including bamboo and acacia. Fragments of reed and/or split bamboo carrying baskets were found. Several pottery lamps were found in form like small plant pots. These contain oil residues of vegetable origin and probably used cotton seeds as moderator. Their position on ledges, or near the pathway suggests that the lamps had semifixed location rather than being carried. Small jars for carrying drinking water or oil were found and some large jars probably used for carrying water out of the mine were also found.

"One has a mental picture of some hundreds of persons at work, some carrying fuel or support timber in, and ore and rock waste out, probably using baskets carried on the head, with others conveying water in a similar way. ... specialised skilled

men would include the fire-setters and timber men who constructed morticed ladders and steps etc."

Fire-setting was the major means of extraction. The characteristic holes created by the fires suggest that the main impact was in the floor with a reduced effect the higher above the fire the flames climbed producing the characteristic arched roof form. Thus sinking a decline was the preferential mode of attack, whilst working up - dip was done by creating and driving forwards holes in the floor. A typical depth affected by a single burn seems to have been 5 cm. Many large pieces of rock, sometimes too heavy to lift, suggest mechanical breaking methods were used, probably using iron tools and perhaps a battering ram. 'Gad' and wedge marks were observed mainly in narrow slits.

Fire-setting must have created major ventilation problems. the combination of particulate material, and oxides of carbon and of sulphur, and of high humidity, must have made working conditions difficult.

Zawar Mochia

Mochia has a series of parallel almost vertical ore bearing beds outcropping as a high ridge for a strike length of nearly 7 km. Beds and oreshoots have been removed across a total maximum width of around 30 m, but this varies considerably. Most of the ridge is characterised by trench type workings or by inclines and shallow shafts; use of round pointed 'gads', and of wedge ended chisels was common and fire-setting has also been used producing characteristic ovoid gallery sections and rouded hollow depressions in walls or roofs, or gallery ends. Small timber stemples, fitted in natural crannies or in holes seem to have been used for climbing, and for supporting waste overhead.

At the western end of the open workings of Mochia, as well as smaller trench workings a large opencast quarry has been developed, 30-40 m wide at its deepest. It is between 10-40 m wide and at least 300 m along the strike. The method of extraction seems to have been to cut upwards and behind individual beds, causing them to fall to the quarry floor. Packs of rubble stone are to be found in two places, built up to provide access to the last working places. Hammer and 'gad' or some form of pick seems to have been used.

Underground ancient working are found almost to river level, to a depth of almost 200 m. Iron 'gads' a draw hoe for filling baskets, an iron pestle, woven basket work, rope and timber have been recovered.

Boroi Magra

This ridge has a number of shallow workings and some deep ones. The use of small martars locally is established which were cut into the rock near shafts, as a means of crushing ore down to coarse sand size.

Rajpura-Dariba Mines

At Rajpura-Dariba metamorphic calc-silicate rocks derived from mineralised sandy dolomite rocks of pre-cambrian age form conspicuous rigdes, with the plain formed from much greater thickness of more easily weathered graphite schist.

There are three lodes in the deposit: the East lode, the North lode and the South lode. Boreholes have proved ancient workings on the East lode at a depth of 254 m, with a sample of timber at this depth radio carbon dated at about 1840 years before present. Ancient working are also found on the South and North lodes, with radio carbon dates for wood samples from South lode from 3120 to 2200 years.

Lead was the chief product, for silver refining, but some copper, probably from secondary mineralization ore, was mined as late as 1831. Metallurgical waste includes lead slags, litharge from silver refining and copper slags but no zinc slag, of both ancient and medieval periods.

North Lode

Both opencast and underground methods are apparent. The earliest workings appear to have been by narrow shafts sunk in ore-bearing beds following apparently irregular deposits. Shafts are common in pairs, often at intervals of only a few metres, and have climbing footholds (*Fig.9*). Some shafts have been sunk in the softer graphite schist to meet the hangingwall of the calc- sillicate at a depth of 8-10 m.

On the hanging wall side of lode particularly some of the pairs of shafts have been joined and enlarged and fitted with large beam slots to form working and hauling platforms. These open out below into large stoped areas 10-12 m high and as wide. There is an example of a cross-cut driven probably to locate another ore-bearing bed a few metres away.

Evidence of beneficiation methods is found in quartzite river pebbles. Deep mortars were found in the rock in one of the mine openings. Iron pestles might have been used, but stone hammers found would have sufficed.

South Lode

The South lode has only one mine opening (old or ancient), but the surface shows many infilled trenches. Probably the quarrying is post-medieval. Underground at a depth of around 100m a number of ancient workings have been intersected; mainly following shoots of lead ore in the footwall of the calc silicate and the underlying graphite schist. These workings are predominantly fireset, mostly near vertical. In one small section timbers up to 25 cm diameter and over 4m long were found, partly worked on the ends by an adze to allow them to drop into slots. This type of timber may have been used either for heavy support, or for spanning large vertical opening, as in one case, a rectangular section shaft 3.5 m × 2.8 m in size, Another chamber had a 3m long timber morticed ladder linking one level with another, with rungs about 45 cm apart. Nearby firesetting used a timber plarform so as to attack the wall above floor level.

A shaft like chamber was some 20 m high, 7 m wide at the bottom and 5 m higher up. A ladder about 3m long links it to another opening.

The two shafts around have ensured air circulation, whilst the timber beams across the main part of the shaft would have continued to divide air flows as well as providing ladder stagings.



Fig.9.A view of chimney foot-holds

The workings continue below water table for some 80-90 m at least. For drainage, presumably oxen or buffalo may have been used on the very large shafts to draw water. Remains of woven baskets, and ropes about 2.5 cm diameter have been found in the workings.

East Lode

More recently extensive timber work on the east side has been revealed for a length of atleast 150 m, radio carbon dated at about 2200 years before present. — "Removal of water from the pit would have been done by human labour, but the use of oxen on wells in this area today suggests their use in the past too".

There are some small and some large mortar holes each about 30 cm across and up to twice as deep with rounded bottoms. These were undoubtedly worked as stamps, using timber shafts presumably shod with timber or iron, to pummel the ore. At this lode probably silver rich oxidised lead deposit of anglesite or cerussite was worked.

Rampura-Agucha Mines

Here the ancient mine workings are preferentially located at the northern limit and in the housing wall of the deposit. A piece of wood from the mine working has been carbondated at 2240 years b.p. *(Table 1)*

A timber recovered from 30 m depth is dated 2356 years before present. Deep workings were formed in the centre of the lode and shafts have been sunk particularly on the hangingwall side to reach the lode at depth.

Most of the workings of ancient age (*Fig 10*) so far revealed are opencast, down to contact zone, with some 30-40% extraction on one section across the width (130m) of lode, to some 15 m depth. Slag dumps occupy some 1800 sq.m. of surface area and are approximately 1 m deep. Analysis of the slag suggests that zinc oxides were being deliberately produced there some 2000 years ago.

There is much silver refining debris. It is guessed that silver content in the deposit worked was as high as 15%.

The weathered gneiss was presumably cut by wedged end chisels rather than 'gads'... on one section of the 375 m berm on the east side of the pit, seven remains or carbonised traces of woven baskets were found (*Fig.11*). In the same location timber supports, with verticals morticed into sole plates have been found (*Fig. 12*). In other areas shafts with footholds had been sunk working almost vertical shoots of ore in a joint or possibly a shear zone..."Galleries visible seem to have been of walking height, the chisel marks in the usually soft rock clearly visible".

Rajasthan was a major mining province some 3000 years ago, with production on a substantial scale continuing 1200 years, under sometimes extreme technical difficulties. Smelting and silver refining were equally technically advanced. Zinc smelting was done as early as 9th century (and there are slight indications of much older origins). It was perfected as an industrial scale process around the beginning of 13th century, in all probability at Zawar. *Fig. 13* shows the clay retorts scattered around the ruins of Zawar which were used for zinc smelting. The early miner located the ore and continued to assure himself that he was mining ore not waste. With poor illumination the main judgment between ore and waste would have been by the heft or "Weight".

For the extraction of ore, metal tools were used in India from an early date. India had iron available for the tools about 2900 years ago (Hegde, 1981) and though a copper based tool has been reported for another area (Allchin, 1962) iron seems to have predominated as wedge tipped chisels, pointed 'gads' hammer pestles and draw-hoes. In hard competent rocks firesetting was widely used first to create a system of cracks which were exploited to extract the ore by chisels or 'gads'.

Shallow mining or outcrop mining seems to have depended mainly on the use of hammer and 'gad' exploiting weaknesses exposed by weathering. Firesetting was occasionally used at shallow depth, and clearly predominated in the hard rocks unaffected by leached solutions at depth.

The problem of roof support at Zawar was simple as the rock is fairly uniform in quality and of high competency. At depth where the rocks are much less weathered, the arched openings are much larger than earlier higher working, and spans of flat roof are up to 20-30 m. Many pillars have been removed by retreat working, in a systematic manner, allowing the maximum depth to be achieved at the earliest with less risk or rock instability and water inflows. At Rajpura-Dariba where rock is weak, large timbers have been used to support both the wall and the roof; and stemples and props seem carefully shaped for the purpose.

The great depth attained at Rajpura-Dariba shows that the practical and economic system of water control had evolved. It is noticeable that on Zawar Mala, with one exception, the openings are placed well up from the floor of the valley so

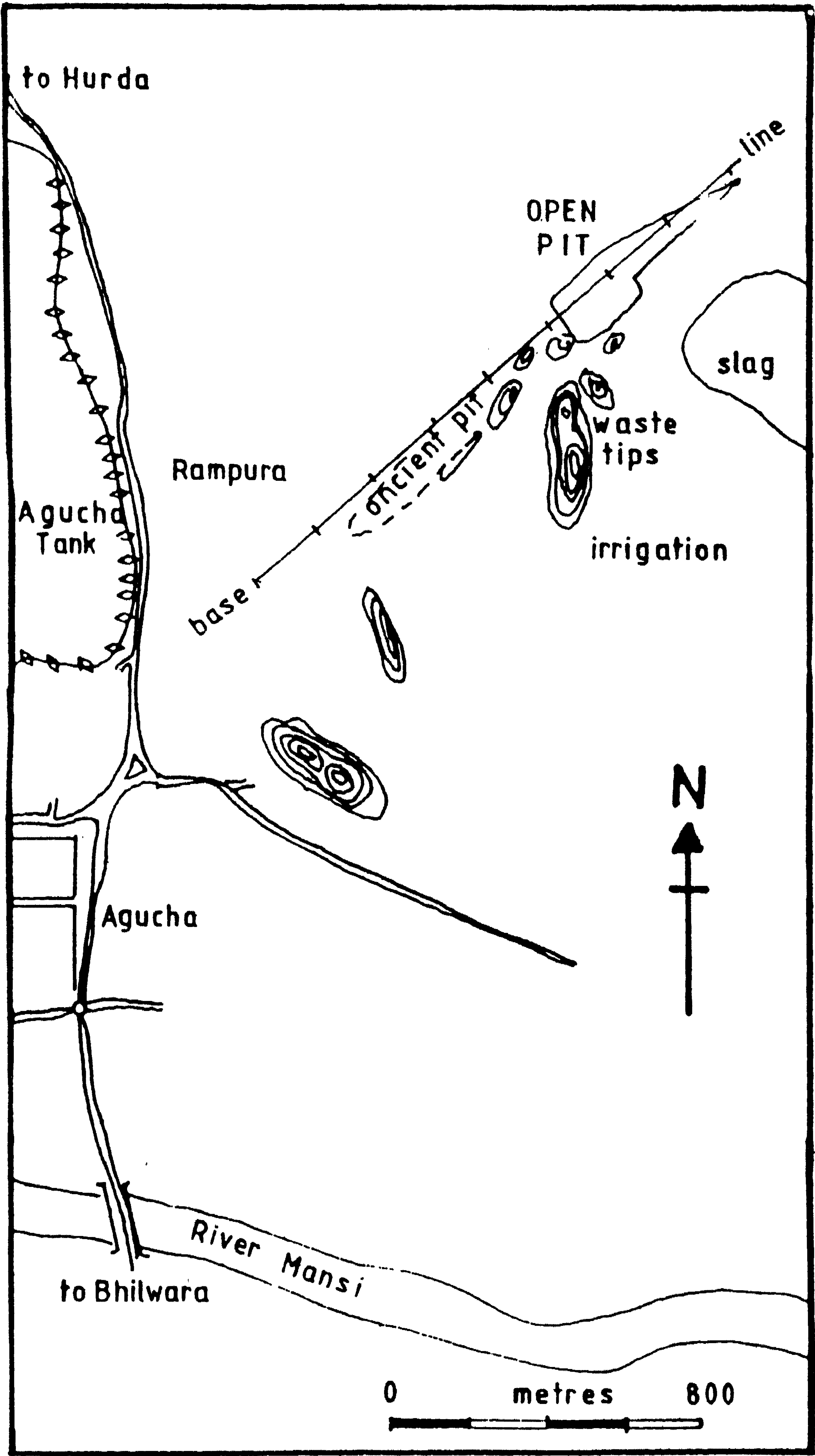


Fig.10.Plan of old workings at Rampura-Agucha

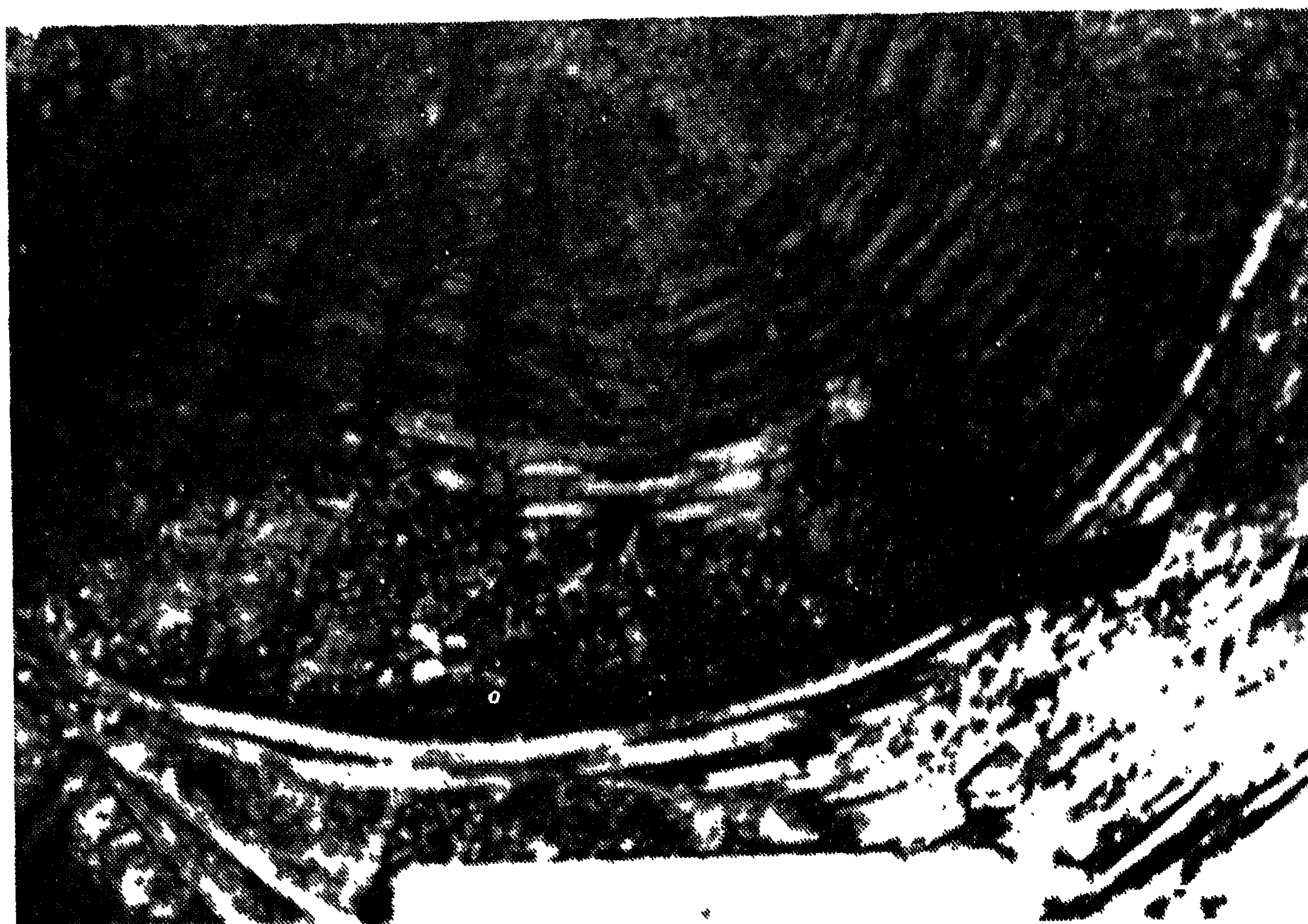


Fig.11.A woven basket

as monsoon water does not rush in the mine. Care must also have been taken underground not to allow water to run to the bottom by the use of launders to bring water to a convenient transport point, and the use of finger stopes and discrete shafts allowed retreat from flooded sections. Most water must have been removed by hand bailing and lifting from the mine, using pots or leather bags. Animals might have been used on deep shafts for winding water.

For ventilation usually the miners relied on natural ventilation. But there are evidences in pairs of shafts and linked finger stopes to suggest that intake and return airways were separated particularly at Zawar Mala and at Rajpura-Dariba.

There is clear evidence of late but still ancient mining in Zawar Mala, above the probable contemporary water table, worked by classical retreat methods, including pillar removal and the system was perhaps deliberately planned.

For transport of ore and material the ancients used good paths and ladderways for large number of people to move round continuously. Rope haulage system have been in use at Rajpura- Dariba, where ropes of 2.5 cm diameter have found. At Zawar mala especially systematic transport systems were developed, with well developed zig-zag paths on slopes, assisted by stone or wood steps or ladders on steeper sections. The size of the passage on the main routes would have allowed loads to be carried in baskets on the head.

For lighting oil lamps were used and there is evidence to show that lights in fixed positions were used at least at Zawar Mala.

Beneficiation process began at the fire-hole or forefield. Since good ore was notably 'heavy' a competent miner would sort it out into waste or ore at the site of

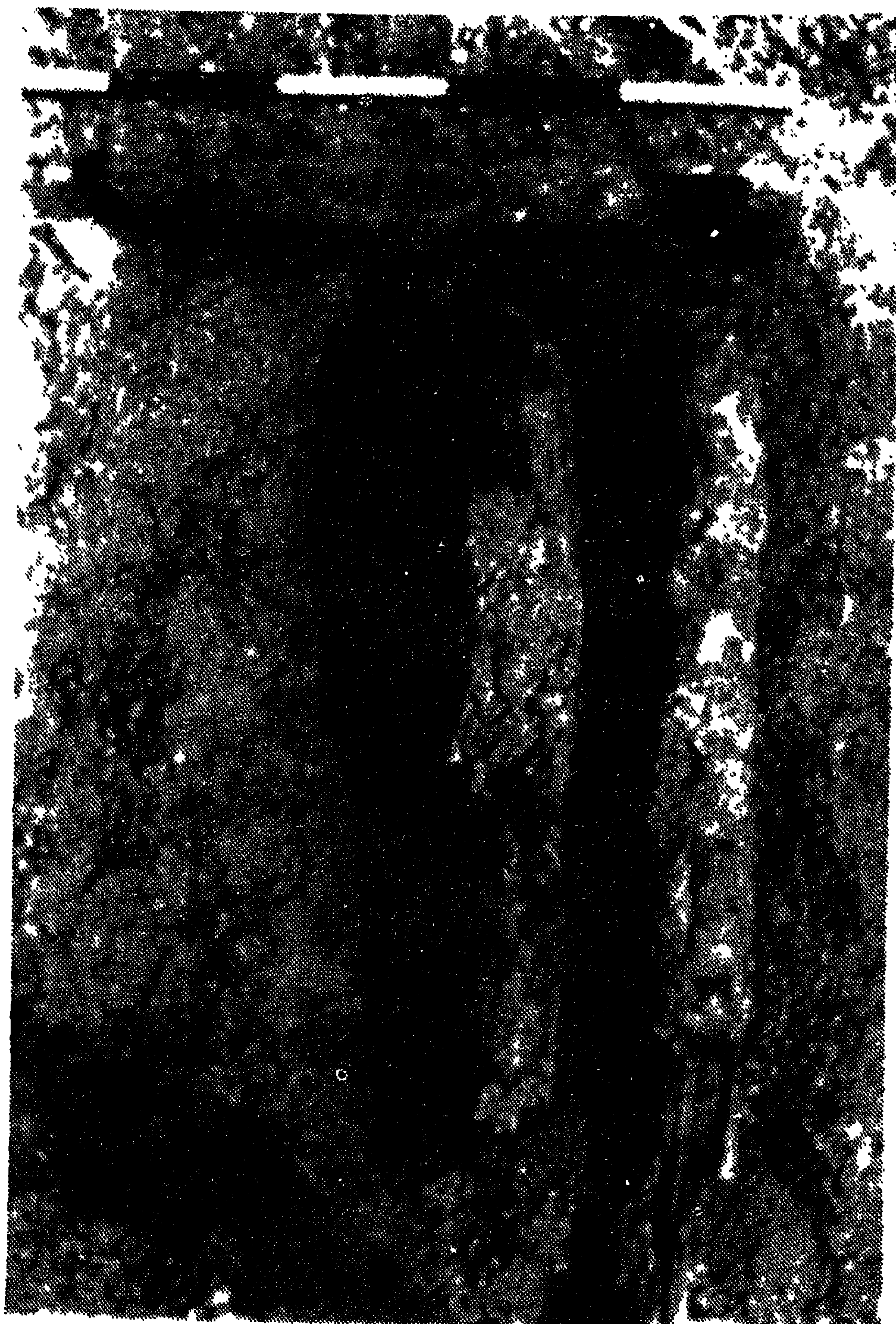


Fig.12. Vertical supports morticed into sole plates

its production. Crushing of the ore in the stone mortars and picking with hand was the common method of ore beneficiation.

Specialists included firemen and timber men and the supervisory staff. Efficient trade and marketing of minerals/ores would have been organised nationally and internationally.

Concluding Remarks

Use of minerals by man dates back to Pleistocene period. In India, in the pre-vedic period mining and use of metals specially gold, silver, copper and gemstones have been mentioned extensively. The vedic period (Circa 1500 B.C.) saw considerable growth of mining and mineral industry. The Rgveda, the oldest composition of Aryans mentions the use of copper, bronze, gold and silver and Yajurveda mentions the use of gold, silver, copper, lead, tin and iron. But the earliest

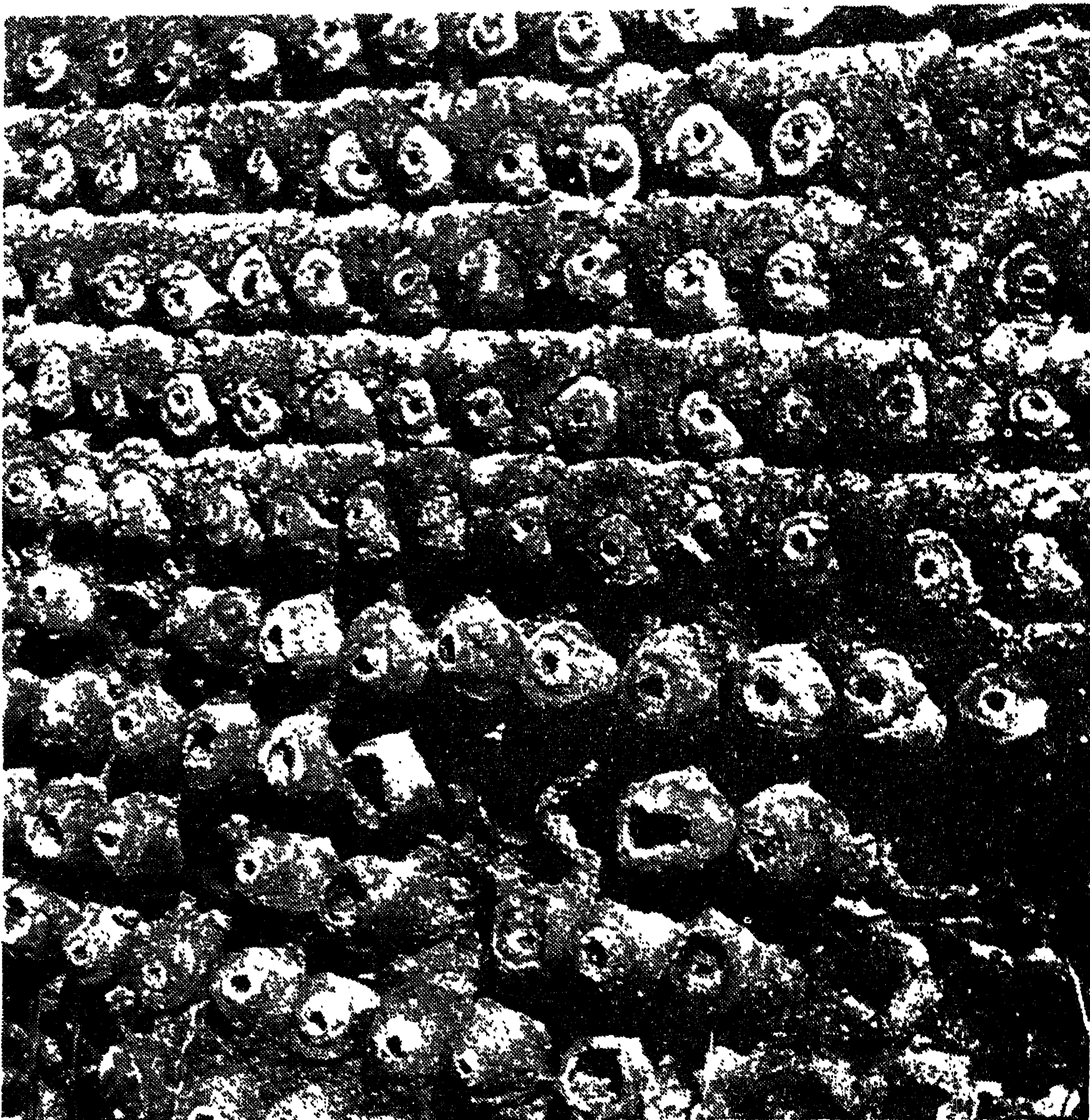


Fig.13. Clay retorts

and most authentic record of information relating to mining and minerals is found in *Arthaśāstra*, composed by Kauṭilya. Metallurgy of copper and its alloys (brass and bronze) was highly developed during this period. By then mining of gold, copper, lead-zinc and silver had fully developed in different parts of the country.

Recent explorations and studies have shown that mining of gold in South India, lead-zinc-silver mining in Rajasthan and copper mining in Bihar and Rajasthan was firmly established as a prosperous industry in ancient India and the mining standards, judged by the standards then prevailing, were quite high.

Invariably for all hard rock mining fire-setting followed by quenching the fire with water was the main general method for creating a system of cracks in the rock mass/orebody which were subsequently exploited for extracting the ore by 'gad' or chisels. Iron for extraction tools came in use long time (some 2900 years) ago.

Pillars were left to support the stopes and weak backs were supported by timber. Evidences of extraction of pillars and planned retreat mining are also available, for example, at Zawar.

The ore was transported out of the mine in baskets by human labour. In some mines a chain of men worked to transport the ore from one man to the other. The working faces were illuminated by bamboo chips and later use of earthen oil lamps is indicated.

Although the ancients had learnt how to deal with water, it was the main inhibitor which limited the depth to which mining could be carried on. All the same, some mines in India descended to great depths. For example, Hutti gold mine reached a depth of 640 ft (195.07 m), a depth not reached by any other mine in the world in those days.

Ventilation of the working places was solely dependent on natural processes. The ancients however, appreciated the advantages of separating intakes and returns and at some mines shafts were sunk at close intervals which were interconnected underground to establish ventilation.

The working conditions were by and large very arduous and risky and took heavy toil of human life as at Khetri.

As said earlier mining of gold, copper, lead-zinc-silver and diamond was highly developed and Indian metals and gems were widely traded and exported abroad.

Acknowledgement

The information contained in this paper is based mainly on the published literature in different journals, books etc. Obviously an exposition of this type may not be free from personal imaginations and guesses of different authors into unrecorded activities of the ancients.

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Notes

1. *ākarādhykṣa śulbadhātuśāstrarasapāka-manirāgajñastaijñasakho vā tajjāta karmakaropakaraṇasampannaḥ kiṭṭamuṣāṅgārabhasmaliṅgaṃ vā ākaraṃ bhūtapūrvam abhutapūrvam vā bhūmiprastārarasadhātu matyārtha varṇa gauravamugra gandharasaṃ parikṣetą* |

[Kauṭilya Arthaśāstra, 2.12.1]

2. *ākramya bājin pṛthivīm agnimicchārucātvam |*
bhūmyā vṛtvaya no brūhi yataḥ khaneṃa tam vayam ||
[Śukla Yajurveda Saṃhitā, 11th chapter, 19 kāṇḍa]

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Metals and Metallurgy

BHANU PRAKASH

Introduction

A large number of metallic objects made of Gold, Silver, Copper, Iron, Bronze and Brass etc. have been found at the Neolithic, Megalithic, Chalcolithic sites and others belonging to the latter period on the Indian Peninsula. *Table 1* gives an overview of India's cultural history and the chronology of the discovery and development of metals technology resulting into Copper Age, Bronze Age and Iron Age cultures. The archaeological approach to this type of classification suffers from the failure of direct application of ^{14}C or other method of dating of the metallic objects. The dating of the metallic objects based on the strata of the excavation sites does not consider the probability of their earlier discovery, utilization and preservation. Spratt (1986),in his discussions on the innovation theory,has considered in detail the steps through which any new discovery and its introduction in the day-to-day life has to pass. According to him these stages are as follows :

(1) Discovery - i.e. an addition on the body of technical or scientific knowledge.

(2) Invention - i.e. the perception of the practical use of the discovered knowledge.

(3) Development - i.e. small scale trials of manufacture and/or use of the invention.

(4) Production and Distribution - i.e. mass scale availability and use of the material in the day-to-day life.

The fifth step in this process is - obsolescence, when any innovation is rejected or surpassed in favour of another superior one, and this is the stage when a metallic object is generally found at the excavation sites except in the case of natural calamities. Thus we see that the discovery of any metallic or non-metallic object or artifact at any excavation site does not take into account the time gap comprising of the first three steps of any innovation and this may lead to inaccuracy in the determination of the exact age of metallic object and the era to which it actually

Table 1 — Indian Chronology of Cultural History and Development of Metals Technology [1,2]

Period	Cultural History of India			Introduction of Metals and Technology
Year	North	Central	South	
1 M to 6000 B.C.	Most probably	Dravidian culture		Native Metal Au, Cu
4000 B.C.	Pre-Harappan Aryans	—	Neolithic and Chalcolithic	Au, Cu and possibly Meteoric Iron
2500 B.C.	Indus Valley Civilization (Glazed Pottery Culture)	Neolithic Culture	"	Ag, Pb, As and Copper Alloys, Foundry Technology
1500-2000 B.C.	Aryan Culture (Vedic Period)	Dravidian and Aryan Interaction		Iron Age Culture, Steel and Metal Working Tech.,.Distillation
600 B.C.	Rise of Magadh	—	—	Amalgamation, Soldering, Brass Gilding etc.
500 B.C.	Persian Conquest and Buddhist Period	—	—	May be Wootz Steel (Matter and Atomic Theory)
321-184 B.C.	Mauryan Dynasty Chandra Gupta and Ashoka Empire	—	—	Cupellation and other refining technology
B.C.				
O Christian era A.D.		Ayurvedic period	—	—
319-606 A.D.	Gupta Dynasty	—	Pallavas	Commercial scale Zn, Brass, Cireperdue Process of Casting
600-710 A.D.	Invasion of Huns	—	Chalukyas and Chola Empire	Extensive use of Iron, Steel, Hg, Zn etc.
1000 A.D.	Afghan's Raid	—	—	-do-
1100 A.D.	—	—	Hoysala	Brass and Bronze castings.
1300-1572	Mughal Sultanate	—	Vijayanagar	Bronze Guns and Metal craft
1498 to 1707 A.D.	"	Portugese in India, Mughals, Maratha	Industrialization of Iron, Steel, Brass and Bronze	
1605-1761 A.D.	British Empire	—	French in India, War with Tipu Sultan	Modern Metal Tech. Iron Guns

belongs. Sorensen (1986) has pointed out that even the acceptance of any innovation may be delayed due to the socio-cultural set-up of the society, and hence its commercial utilization may be delayed. Saunders (1977) and McDonell (1984) have discussed the life cycle of the discovery of any metal and its objects. This cyclic discovery and discarding of metallic objects is shown in *Fig. 1* with the introduction of one more step viz. 'Preservation'. Here it is assumed that at the time of discovery of the metals they must have been a very scarce and costly commodity and hence there is high probability that the earlier metallic tools, hunting implements and other objects must have been preserved for centuries before they were destroyed or lost, and they could not have been thrown away like Stone Age tools. *Fig. 2* shows the 'time-gap' between the discovery and utilisation of a number of inventions in Europe as plotted by Saunders (1977).

As regards the initial scarcity and high value of the material a *Śruti* from Ṛgveda as translated by Banerjee (1929) and quoted by Kulkarni (1989) is given in *Fig. 3*, which mention the presence of steel and its high value in the Vedic period.

The discussions presented here are based on the archaeometallurgical studies, which is a hybrid of the combined study of archaeological findings of metallic objects and their metallurgy. The desiderate for such evaluation are as follows :

(i) occurrence of the mineral and their processing technology,

(ii) details regarding excavation sites, settlement and industry,

(iii) experience in the related field,

(iv) evaluation of socio-economic network,

(v) environment for the growth of the technology.

India has been blessed with vast deposits of many minerals and precious stones and many of these have been in use even during the prehistoric era as ornaments

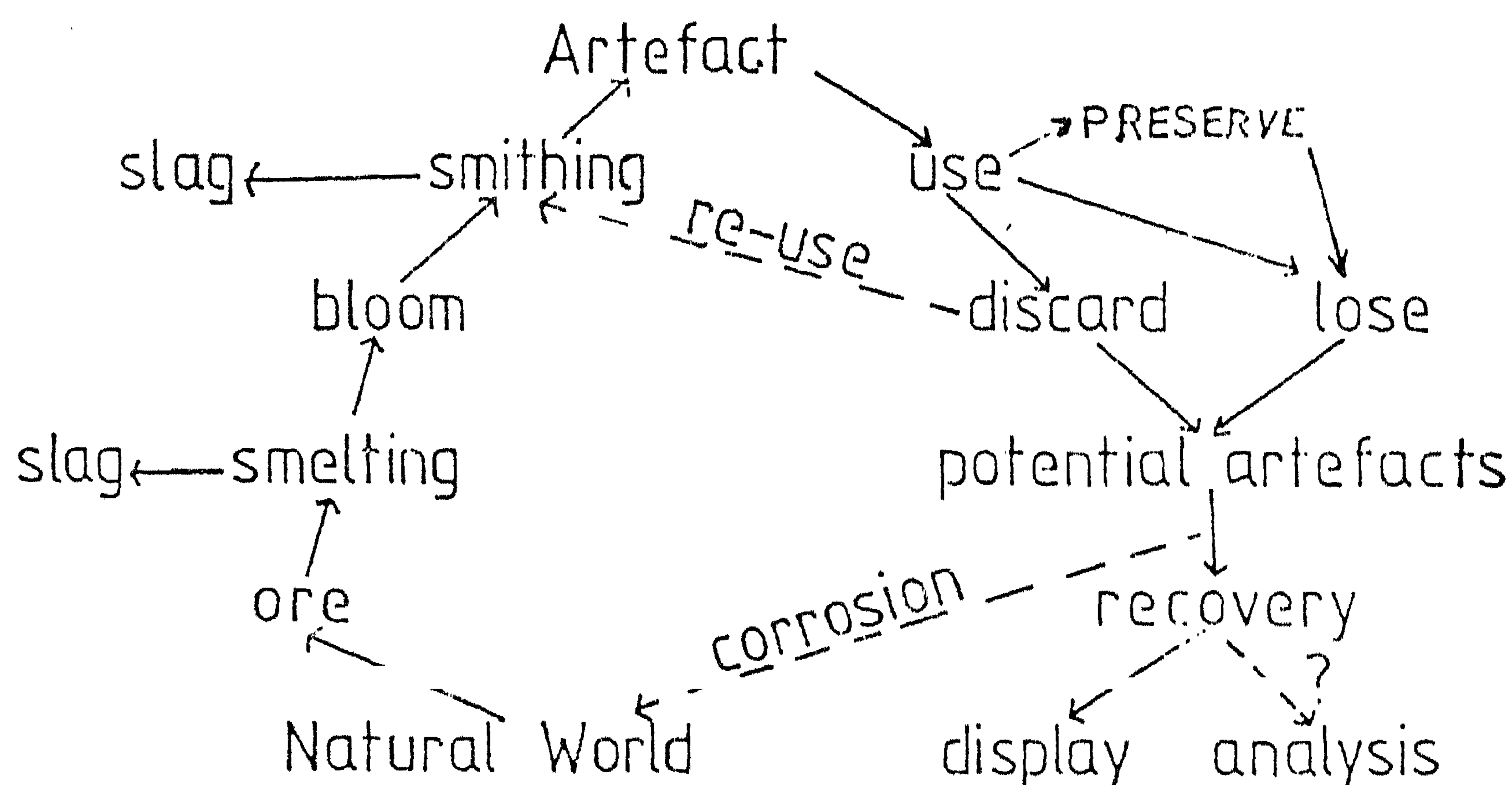


Fig. 1. Life cycle of archaeological metallic artifacts

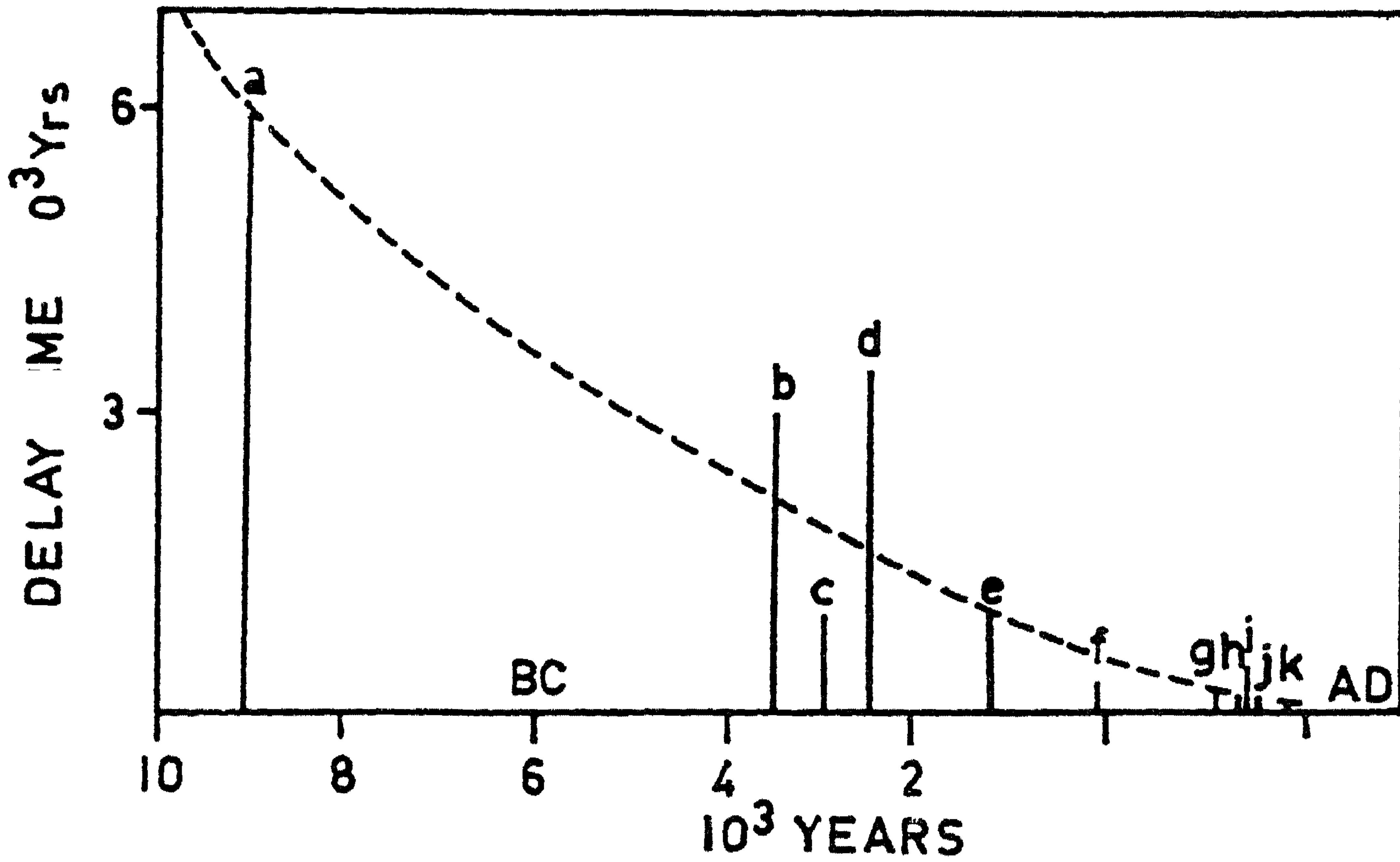


Fig. 2. Delay-time for various innovations and their commercialization

जरतीभिः औषधिभिः पर्णेभिः शकुनानाम् । ऋग्वेद ऋ 9.112.2
कर्मारो अश्मभिः द्युभिः हिरण्यवन्तमिच्छति
इन्द्रायेन्द्रो परिश्रव ॥

कर्मार यानि लोहार लकड़ी के टुकड़े लोहे की खनिज के साथ रखता है । तालपत्र में लकड़ी के टुकड़े रखते होंगे । लोहे के खनिज के टुकड़े और तालपत्र लकड़ी के टुकड़े अर्क (asclepias giganta) यानि आकन्द वृक्ष के पत्तों से (पर्णेभिः) ढकते थे । खनिज के पत्थर (धुमिः अश्मभिः) लकड़ी के टुकड़े के साथ तपाने से जली हुई लकड़ी का कोयला (कार्बन) लोहे के साथ घुलता होगा जिससे लोहे का इस्पात में परिवर्तन होता होगा । कार्बन की मात्रा बढ़ाने के लिह शकुन यानि हंस पंछी के पर भी डालते थे । हंस के पंख में 90% वाष्पशील[7] द्रव्य और 10% कार्बन होता है या शकुन पंछी के परों का धोंकनी निर्माण करने के लिए उपयोग करते होंगे । ऋग्वेदकाल में इस्पात बहुत महंगा होता था । इसीलिए यह लोहार धन-सम्पन्न (हिरण्यवन्तं) व्यक्ति की प्रतिक्षा करता था ताकि उन्हें यह इस्पात बेच सके । इसी लेख में आगे बताया गया है कि उन्नीसवीं सदी तक भारतीय ऋग्वेद दिए हुए इस ऋचा में वर्णित पद्धति से इस्पात निर्मित करते थे ।

Fig. 3. Sanskrit text regarding production of steel as mentioned in Ṛgveda in Rica 9.112.2

and source of pigments to decorate the human body as well as surroundings. The recent discovery of stone age tools by Rendell and Dennell (1987) at Jalapur and Soan syncline section near Mohenjodaro site belonging to the Shivalik period has been evaluated to be atleast two million years old i.e. one of the oldest in the world. Rendell and Dennell have opined that this important discovery may change the whole chronology of the evolution and dispersal of humanoids both in Africa and Asia, and possibly even the cultural history of the whole world. So far as the use of metals is concerned the oldest archaeological finding is at the sites belonging to the Harappa and Mohenjodaro culture and at some ancient cairn burials of South India. These sites have been rich in Gold, Silver, Copper and Bronze artifacts. The technological skill of the ancient craftsmen is evident from the famous bronze statue of the dancing girl found at Mohenjodaro and their skill to drill fine holes in mineral beads using a fine hollow metallic drill. The Mohenjo-daro bronze dancing girl was presumably made by the cireperdue process of casting.

The Vedic scripts are full of the mention of Au, Ag, Cu, Fe and their alloys as well as their use in various religious rites. Prakash, S. (1965) has described a true ancient scenario by mentioning that in Vedic period all the science has grown with the *Yajna* which had almost become an open air laboratory and observatory. He has also warned that one has to be cautious while using the Vedic terminology which are markedly different from the terminology evolved in different disciplines of knowledge at a latter stage.

The social life of the Vedic period has been mostly agriculture based and people had great faith in the religious rites and the philosophy of life. The scientific principles mentioned in the four epics might have been a part of their daily routine. While it had helped in maintaining the socio-economic order and preservation of culture it also had prevented the learned craftsmen from the preparation of written records of their experience and knowledge which were generally transmitted from father to sons and other members of the family or clan.

There is no doubt that during the Vedic period the opportunity and the atmosphere were congenial for experimentation and development of new technologies, but owing to the religious beliefs and rituals associated with each experimentation, the free dissipation of the knowledge was prevented. How long this tradition has been in-vogue before the written records of these epics and processes were prepared is difficult to be decided and hence the exact history of the discovery of the metals and metallurgy in the Indian Subcontinent is not known. But it is certain that many of the common metals were known during the Vedic period and they were being used for the manufacture of various tools used for agriculture, defence, and transport by land, sea and probably also by air (*vimān*) using steam and other energy sources. The need for development of such technology has been described in *Rgveda*, *Śruti* 1.1, 1.3.1, 1,3.2. and in *Yajurveda* 1.4 and 4.33.

Discovery of Metals

So far as the discovery of metals and the development of metals technology is concerned the universal opinion is that the focal point of these discoveries is Iran and its nearby area and in India the metals technology has been introduced by Aryans or Hittites who migrated from that area, but in a recent lecture Sharma,R.S.(1988) has opined that Aryans were originally Indians and most of the discovery of metals technology is indigenous. It is an universal belief that native metals like Gold, Copper and probable Meteoritic Iron have been the first to be discovered as early as 6000 to one million years before Christ.

The golden yellow glitter of the native Gold has been probably the main force behind the development of the metals technology although this has been a worthless metal for the Stone Age men who wanted to fabricate war tools like arrows, axes and hammers from this metal. Mahamud (1988) has rightly mentioned that the glitter of Gold has been destined to play the most sinister role in the history of mankind and for the sake of possession of this metal many blood thirsty wars have been raged and monstrous crimes committed.

According to Prakash, S. (1965) the discovery of fire (4000 B.C.) has played a vital role in the extraction and processing of metals. *Atharvans* or *Aṅgiras* or *Athar Vaṅgīras* are supposed to be the first to discover the fire. It is believed that the legends associated with the Promethens in the Greek Mythology actually had its

अश्मा च मे मृत्तिका च मे गिरयश्च मे पर्वताश्च मे सिकताश्च मे वनस्पतयश्च मे हिरण्यं च मेऽयश्च मे श्यामञ्च मे लोहञ्च मे सीसञ्च मे त्रपु च मे यज्ञेन कल्पन्ताम् ॥ १३ ॥

रत्नवान् धनवान् आत्मा । भुरिगतिशक्वरी । पंचमः ॥

भा०—(अश्मा च) सब प्रकार के पाषाण, हीरे आदि, (मृत्तिका च) सब प्रकार की मिट्टियां, (गिरयः च) पर्वत, इनसे प्राप्त भोग्य पदार्थ, (सिकताः च) बालुकामय देश, (वनस्पतयः च) वनस्पतियां, (हिरण्यं च) सुवर्ण, (अयः च) लोहा, (श्यामं च) श्यामलोह, (लोहं च) कान्त-लोह, कान्तिसार आदि (सीसं च) सीसा और (त्रपु च) टीन, रांगा आदि ये सब धातु भी (मे यज्ञेन कल्पन्ताम्) शिल्प, रसायन, भूगर्भ विद्या आदि के प्रयोग से मुझे प्राप्त हों ।

Fig. 4. Sanskrit text on the evolution of iron and other metals as mentioned in Yajurveda in Chapter 8

roots in India and the word Promethens comes from the Sanskrit word *Pra-Mantha* i.e. fire produced by manthan or rubbing action. In this context a *Sruti* from *Yajurveda* is quoted in *Fig.4* which clearly mentions the production of metals from *Yajña Kuṇḍa*.

Thus we see that 'Agni' has played a vital role in the extraction and working of metals. In the present chapter the metal technology has been mentioned from the point of view of their occurrence in nature, the scientific and technological feasibility of their extraction and study of the thermomechanical treatment of these metals for the production of various objects found in daily use of the ancient Indians.

These descriptions are presented here in three sections viz. extraction of pure metals like, Gold, Silver, Copper, Iron, Tin, Lead, Zinc, Mercury etc., the technology of their alloying and the technology of fabrication and thermo-mechanical treatment.

Metallurgy of Pure Metals

(I) Gold

According to Gowland (1912) and Bhardwaj (1979) it is extremely probable if not absolutely certain that Neolithic men would have first become acquainted with native Gold but they would have been disappointed in its use to shape hunting tools and war weapons. In our country not many Gold artifacts dating to Pre-Harappan period have been reported although in *Ṛgveda* Gold and its alloys with Ag and Cu have been mentioned in many places, such as, I-85.9, 88.5, 67.3; II-37.9; V-54.15, 57.1, 60.4; VIII- 7.27-32 etc. In Vedic literature this metal has been mentioned as *Hiranya* probably because of its high corrosion and oxidation resistance and the practice of its preservation through generations. The recurrence of this metal in the Chalcolithic period is more common and many artifacts have been reported from South India.

This metal has its mesmerising power in its shining bright deep yellow colour which has not got tarnished even by the stains of human blood. In human civilization it has been named as the most sinister and deadly metal although due to its ductility and softness it had proved worthless for making any war weapon. This is so ductile that one gram of the metal can be drawn into more than 1.24 km long wire without any intermediate annealing.

Marshall (1902-1903) has remarked that the Gold frontlets or dead man's mask of the Adichanallur excavations are made of so flimsy gold leaf that in all probability they could not have been used in real life and these have been most probably used as substitutes for the dead. This also indicates the economic aspects of this metals use in the ancient times. The custom of tying gold plates or 'Diadams' is still prevalent in some parts of Madurai, and in North India it is customary to put a small piece of the metal in the mouth of the dying person.

Native Gold has been found in this country in three forms :

(1) Alluvial sedimentary deposits at shallow depth in the river basin. In Nilgiri hills such deposits have been worked upto a depth of 25 m or more.

(2) As fine particles mixed with the river sand. Rivers of Sindh, Sutlaj and other rivers of Kashmir, Ganges, Swarna Rekha, Godavari and many other rivers of South India have been reported to carry gold fines in their sand. Kuppuram (1983) has reviewed such deposits in great detail.

(3) As metal nuggets and streaks in quartz veins at Kolar and Hatti Gold Mines.

(I.1) Process of Extraction

The most common process of separation of native Gold from the sand and alluvial soil or quartz rock has been by gravity separation or panning. In this process the quartz rock or the hard soil is first crushed to fine size to liberate the gold particle and then separate it by suspending the mixture in water.

When the pan containing the suspension is agitated under water gold particles settle at the bottom of the pan and the sand and soil are washed away. For large scale working big pans were hung in the river water through a sling so that the mixture could be easily agitated. After the Gold particle was separated from the gangue (Qz and clay etc.) it was sold to the Goldsmiths for melting, refining and shaping of the metal. Dikshitar (1951) has mentioned that the labourers employed for Gold washing were known as 'Sonwals'. McCrindle (1901) has mentioned that in Assam Gold Washing was being carried out at Suparnakudya (now Sonkudita) even in the 18th century and Sonwals used to pay custom duty annually to the Government in the form of Gold fines worth Rs.5/- During the Ahom's rule about 10,000 people were employed in this trade. Sharma (1992) has reported that gold panning is being carried out even today by tribals of Rajgarh from the Eeb river, a tributary of Mahanadi and they are able to extract 4200 kg of gold per annum.

The second process of extraction of this metal is by the process of amalgamation with Mercury and recovery of Gold by evaporation and distillation of Hg. This process has also been known to the ancient craftsmen and it was also used for gilding of objects made of copper, bronze and brass etc.

Kolar and Hatti Gold mines were being worked even in the prehistoric times and as mentioned by Rao, S.R. (1973) the spectral analysis of the Gold objects of Indus cities and Kolar have shown high degree of similarity. Both the metals are in alloy of Au-Ag known as 'Electrum' instead of pure Gold. It has been proved beyond doubt that the South Indians had learnt the technology of mining Gold at these mines and established the smelting technology on commercial scale and the metal was being traded through Lothal by sea to Harappa, Mohenjodaro and even Egypt, Greece and Rome, Africa etc. even as early as 2500 B.C.

(I.2) Technology of Gold Working

Most probably the first Gold piece used for shaping into a simple ornament like spherical or cylindrical bead or a wire for making bangles was a small nugget but latter-on smelting and refining techniques were developed. Pure Gold melts at

1063°C which could be achieved easily in charcoal fire. The Gold sand obtained by panning was melted in a crucible and refined by the addition of fluxes like borax and a mixture of Ammonium Chloride, Borax and Ammonium nitrate in the ratio 6:1:3. The method of separation of Silver from Gold was known as 'Niyaria' and the craftsmen practicing the separation of Gold and Silver were known by this name. Even today about 300 families in Mirzapur are practicing this trade for separation of various metals like, Au, Ag, Cu, Ni, Zn, brass etc. from the dross obtained from parent metal industries.

The purified metal bar or ingot was worked by forging, punching, embossing etc. for the production of various ornaments having intricate designs. Even rolling and wire drawing was known to the ancient craftmen. Gold coins were either made by die casting in clay moulds or by the technique of punch marking and the quality of the metal was judged with the help of 'Touch Stone' and coin's weight was accurately measured. *Arthaśāstra* of Kauṭilya gives detailed account of the knowledge of minting of coins and production of other objects and the technology of gem setting. They had also learnt to produce Au-Ag and Au-Cu alloys and the use of gold solder (Au:Ag, 8:1) and the ways to improve the golden colour finishing of the joints as early as the vedic period. Today it is well known that Au-Ag have a Eutectic type phase diagram whereas Au-Cu have complete solid solubility and alloying with these metals impart strength, hardness and various shades of colours to the metal as well as lower the melting point of the alloy. As mentioned earlier the technique of Hg amalgamation and gilding was also known to the Indian craftmen from the very early times.

As regards the trade with foreign countries Prakash, S.(1965) quotes Greek and Roman historians giving an account of the Indian Gold and Silver. Curtius Strobo and Philostratus mention the use of these metals in Ancient India. The accounts of Old Testaments show that Ophir mentions the export of Silver and Gold from India. Megasthanese has also mentioned the mining of these metals in various parts of India in the Neolithic-Chalcolithic and Megalithic period. Allchin (1968) has mentioned that Greek Drahams and Roman Dinars made from Indian Gold were in circulation for trade and often smelted for reuse. During the period of Asokan Empire its capital was known as *Suvarnagiri* and it was known for the Golden splendour.

(II) Silver and Lead

Sneed et al.(1954) and McDonald (*see* Butts and Coxe, 1967) have mentioned that just as *Svarṇa* (Gold) has been related to Sun or Sanskrit word *Jval* (to shine), the brilliant white metal silver has been related to Moon and earlier it was called luna. Silver nitrate is still called Lunar Caustic. The Latin name 'Argentum' also has its origin in Sanskrit and it comes from the Aryan origin, meaning shining white metal.

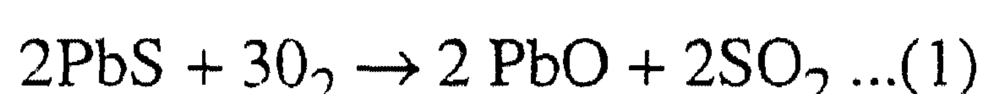
This is the second metal to have attracted the fancy of ancient Indians as a domestic metal which had no value for the manufacture of tools and weapons. The introduction of this metal in the ancient Indian Culture is relatively late because of its non-availability in the nature as virgin metal, i.e. very rarely it is found in the

native form. McDonald writes (*see* Butts and Coxe, 1967) that the discovery of virgin Silver was probably due to the natural fire in some forest where the exposed Argentiferrous Galena (mixed sulphide mineral) was roasted and then reduced resulting into the separation of this metal. Archaeologically speaking very few silver artifacts have been found dating back to Harappan period. A silver dagger belonging to 2700 B.C. from Harappa is being preserved in the National Museum, Delhi.

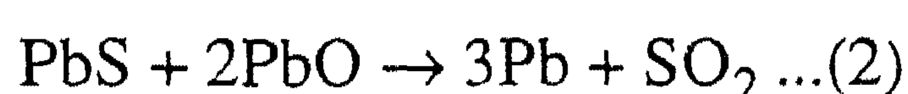
Since Silver (M.P. 962°C) has been found to occur in nature either as AgCl (Cerasgerite) or Ag_2S (Argentite) associated with Galena and/or Sphalerite or mixed sulphide ores, the extraction of this metal is said to be started in 3rd or 4th Millenium B.C. with the development of the technique of treatment of sulphide minerals viz. roasting and reduction smelting. During the extraction of lead from PbS or PbO, Ag_2S also gets decomposed and reduced easily (at 470°C) and it readily alloys with metallic lead at 1000°C hence the metallurgy of lead is being described along with this metal.

Lead artifacts have been reported from the Harappan period, although, due to its softness, it did not find much use in this period. It is one of the softest and heaviest metal having shining grey lustre which leaves a black streak on paper.

It is so soft that it can be scratched even with nail hence it's use has been mostly for the manufacture of cheap jewellery dies or pattern for shaping other metals, and as a hardner in copper alloys.In South India lead coins have been in use in Ist-2nd century B.C and it was the chief coinage metal for considerable time. It melts at 327°C and its B.P. is 1525°C. Besides PbS (Galena) it also occurs in nature as PbO i.e., Massicot and Litharge (Yellow in colour), $PbCO_3$ or Cerussite and white lead $PbCO_3.Pb(OH)_2$ (white powder) or $PbSO_4.PbO$ (white pigment). Lead might have first been recognised as these coloured pigments used for body decoration and during use it might have fallen in the compfire producing metallic lead, because these minerals get decomposed easily to PbO and subsequently reduced to liquid lead at 500°C. The reactions occuring during the roasting of Galena are -



$$2PbS + 3O_2 \rightarrow 2\,PbO + 2SO_2 \quad ...(1)$$



$$PbS + 2PbO \rightarrow 3Pb + SO_2 \quad ...(2)$$

and finally PbO is reduced by C at 500°C or by CO even at lower temperature.



$$PbO + C \rightarrow Pb + CO \quad ...(3)$$



$$PbO + CO \rightarrow Pb + CO_2 \quad ...(4)$$

Since liquid lead readily alloys with silver one of its major use was to first produce this alloy by coreduction of Pb and Ag minerals and then produce pure Silver by the process of cupellation. Bhardwaj writes that these processes were known during the Harappan period.

(II.1) Occurrence of Silver and Lead Minerals

In Indian subcontinent Galena is found in Rajasthan at Zawar and in small amounts in Kashmir, Garhwal in Uttar Pradesh, Bihar and Kerala. One of the biggest deposits of Galena and Ag_2S (Argentite) is found in Burma at Bawduin.

Such deposit of Argentiferrous Galena is found in Zawar and it has been reported to occur in Bihar, Orissa and Kamalpura. Sarkar (1971), and Butts and Coxe (1967) have reported large deposits in Burma at the Namtu and Bawduin mines where signs of ancient working of silver and lead have been found, and Burma is one of the major silver producer even today. Silver has been also reported to be produced at Ananthpur Gold field in Andhra Pradesh. There has been also evidence of the trading of Spanish Silver in exchange of Indian species.

(II.2) Production of Lead and Silver

As discussed earlier PbS after roasting gets converted into PbO and this can be easily reduced at 500^0C to molten lead. The process used in ancient India at Zawar was most probably 'Ore Hearth Process' where the roasting and reduction of rich Galena is carried out in an open pit furnace. *Fig.5* shows a sketch of such a furnace as reported by Raistrick (1927) and referred by Tylecote (1976). In such a furnace temperature as high as 1000^0C can be easily obtained under natural draft and the reduced metal flows out and gets collected in the front pit. At this temperature Ag_2S also gets decomposed, reduced and forms an alloy with molten lead. The details of this process has been mentioned by Sevryukov (1975).

Silver metal was obtained from the alloy of Pb-Ag by reheating it in a shallow hearth furnace having the bottom prepared with bone charcoal. During remelting of the alloy it is subjected to oxidizing condition by blowing excess air when lead gets preferentially oxidized to PbO (litharge) which has a very low melting point. This molten litharge is skimmed off and partially absorbed by the furnace hearth. This process is known as 'Cupellation'. At the end of the refining process purified liquid silver is tapped out and cast into ingots. Although no clear evidence has been found at Zāwar of any such furnace or the remains of Litharge but it has been known in ancient times for the production of lead and silver. Litharge might have been reduced in another ore hearth furnace to produce metallic lead. Kautilya's *Arthasastra* states the following details of the process of cupellation for the purification of silver.

"The pure and impure silver may be heated four times with $CuSO_4$, mixed with powdered bone (*Asthitutha*), again four times with equal quantity of lead and again four times with $CuSO_4$ (*Suskatutha*), again three times in a skull and lastly twice in cow dung. Thus purified silver is obtained. This process has been also quoted by Ray (1956) and Bhardwaj (1979). Bhardwaj (1979) has written that this process of cupellation for the production of Silver and Lead was well developed in the 2nd half of 3rd M.B.C.

(II.3) Mechanical Working of Pb and Ag and their Uses

As mentioned earlier Lead being a very soft metal it did not find much use in the early days but in the latter period it has been used for the manufacture of sanitary pipes, moulding dyes, thin wire or rod for applying surma and probably also as a

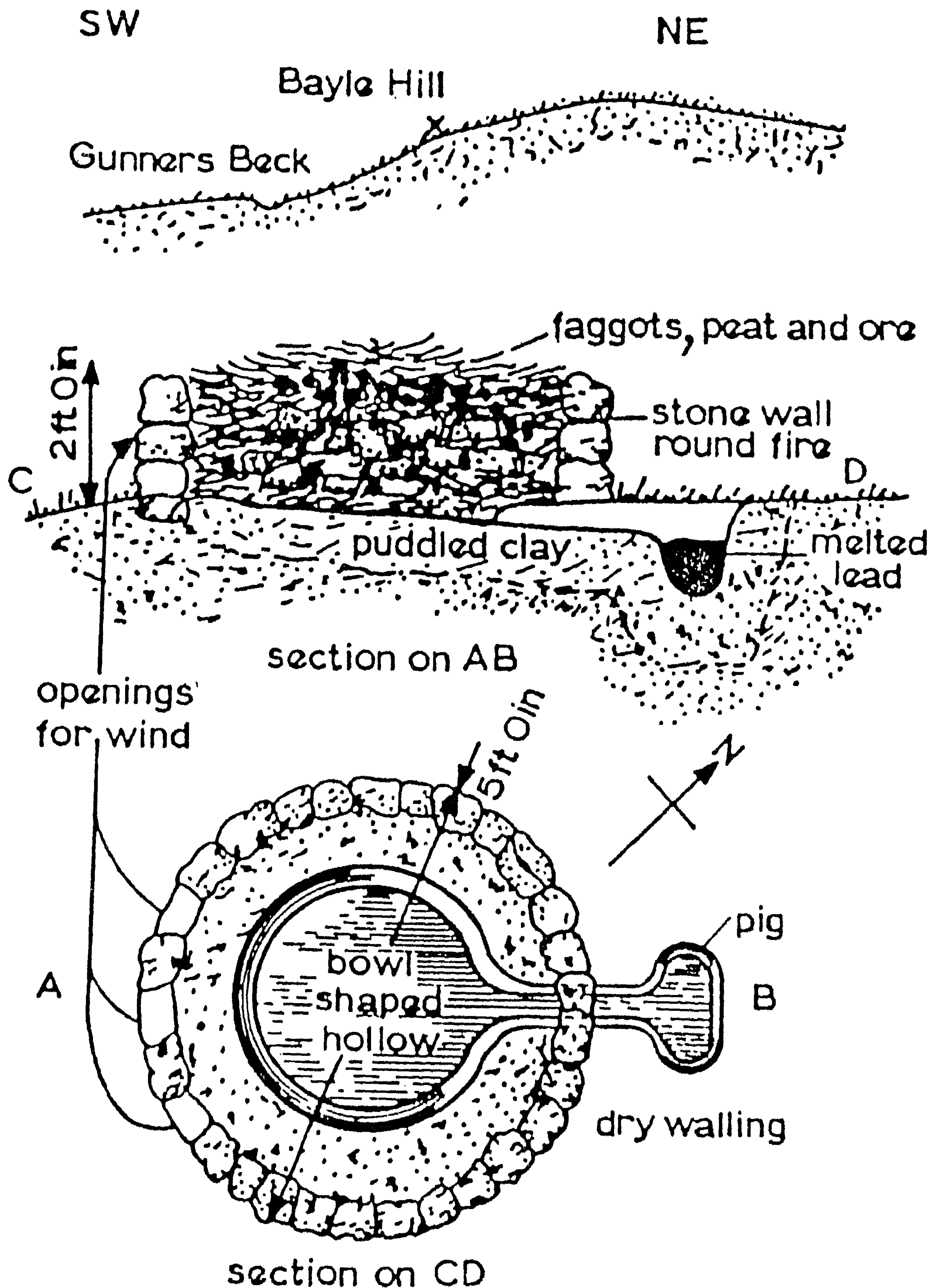


Fig. 5. Early 'Ore Hearth' Lead Smelting furnace as described by Raistrick

base material for engraving and embossing Gold and Silver sheets and foils. Jeyaraj (1990) has mentioned the use of cast lead coins in South India in the 2nd to 3rd century A.D. possibly belonging to Sangam period. Lead compounds also have been used for glazing potteries and in the manufacture of glass. Evidences have indicated the use of this metal to prepare Pb-Sn alloy used as solder to join pieces of copper and bronze. In latter period lead has been extensively used for preparing projectiles for slings and catapults, bullets, cannon balls and cast shots etc.

The shining white colour, high corrosion resistance and the non-tarnishing properties of silver attracted the attention of the primitive men and they found its use in making ornaments, utensils, decorative pieces and other house hold articles. It has also been used for the manufacture of various weapons for decorative as well as ceremonial purposes. The high ductility of the metal permitted it to be forged into sheets and foils used for making utensils having intricate embossed designs, as a sheet covering on various wooden objects studded with jewels for the use of rich men and kings. Its very thin foil has been used to cover various food dishes. This metal has been found also to have medicinal properties and used in the ancient Ayurvedic medicinal system.

The use of this metal as coins has been rather late. It is only in 600 B.C. that punch marked coins have appeared and in the latter period Silver has been popular as coinage metal. In the Gupta period Copper has been deliberately added to economise the consumption of silver as well as increase the wear resistance of the coins. Kauṭilya's *Arthaśāstra* gives a vivid account of minting such punch marked coins. In the latter period other coins have been produced by rolling silver pieces into sheets of uniform thickness and cutting it into equal square pieces. The identification marks were punched on these pieces and their weight was controlled by cutting away the metal from one corner. In recent years Saran (1985) and Prasad, B.(1990-91) have analysed and studied the microstructure of a number of Ag-Cu alloy coins from different heads and they found the alloy composition to be consistent in each group.

(III) Copper

In lithic societies the use of coloured minerals like iron oxide, leaa oxide and blue and green coloured Azurite (Hydrated copper carbonate) has been very common as cosmetics, colours used for decorating hutment walls and pottery, and their use in religious rituals and funeral practice. It is possible that accidental fall of the copper mineral in the fire has given rise to the copper age around 4000 B.C. According to the archaeological evidences this metal is probably the fourth in the series to attract the attention of mankind and give a new dimension to the human culture by providing new fighting and self-protecting power in the hands of mankind.

The discovery of this metal marks the beginning of the Chalcolithic period and the Copper Age when man started using metal instead of stone and clay to fabricate his hunting tools, domestic utensils and many other things like ornaments, decorative pieces, mirror etc. The properties of this ductile reddish coloured metal having a melting point of 1083^{0}C were further improved in the latter period by alloying with Pb, As, Sn and Zn, and some of these produced yellow coloured alloy similar to that of Gold. Copper sulphate mineral was given the name 'Fools Gold' owing to its shining yellow colour.

The first and oldest evidence of copper artifacts in India come from the Nal Cemetery dating back to 3rd M. B.C. i.e.. the same period as in Iran. Tylecote(1976) is of the opinion that the technology of production and use of copper in this country was imported from South Iran along the Persian Gulf i.e. by sea route rather than over the difficult land route through Northern Baluchistan or Afghanistan. If this

is true the Indian society developed at Lothal had trade links as early as 3rd M. B.C. i.e. even earlier than Harappan period. Forbes(1964) has mentioned that King Devius of Iran had a brass cup dating to 522 to 486 B.C., and the origin of this cup most probably belonged to India. This leads to the conclusion that the process of extraction of copper was probably known to Indians much earlier than 3rd M. B.C. and it contradicts the views of Tylecote. The theory of indigenous discovery of copper production technology is further supported by the presence of 4.8% Ni and 2.14% Pb in the copper artifacts found at the Harappan sites, whereas the Iranian copper is rich in Arsenic. the copper sulphide ores found at Khetri and Maubhandar have been found to be rich in nickel.

Rai(1965) has mentioned the discovery of hollow copper, Gold and Silver beads belonging to the Harappan period which were manufactured in two halves and then soldered together. These beads have been threaded in copper wire to form a necklace. At Chinkudaro three types of copper bangles belonging to the same period have been reported. Out of these one type was made from 3.5 to 5.05 mm round copper wire, the second type was semicircular in cross-section with the flat side making the inner side of the bangle. The third type had been hollow from inside and it was made by shaping copper sheet. At Lothal a thin hollow copper pipe has been found which was probably used to drill holes in Gems and glass beads. The massivity of copper objects made in the past can be judged from the tapered copper bolt 620.0 mm in length and having 49.15 mm diameter at the two ends and 56.9 mm at the centre. This bolt has been recovered from an Ashokan pillar found at Rampurva near Nepal dating back to 3 century B.C.. and it is now preserved in the Calcutta National Museum. This bolt requires atleast two persons to lift it. The copper Chariot from Daimabad Hoard has been cast in one piece by the cireperdue process. It is now preserved at the Prince of Wales Museum, Bombay.

The use of copper has been mentioned as *Lohitya* and *Loha* in Vedas and other ancient literature. This has been reviewed in great detail by Kulkarni(1989) and Joshi(1970), Bhardwaj and many others. *Rasa Ratnasamuccaya* gives a vivid account of the processes of extraction of copper and its use in Ayurvedic Medicinal system. In this book copper has been classified into two qualities i.e. one the pure (Red) copper from Nepal and the other impure or black copper (Malecch). The Nepal copper was of high purity (99.5%), brick red in colour and very ductile whereas the impure copper contained copper oxides and other impurities like Pb, Sn, As, Zn etc. which made it hard and brittle.

(III.1) Natural Resources and Extraction of Copper

Copper occurs in nature in native form and most probably man's acquaintance with this metal was in this form, which could be hammered i.e. cold worked to make various hunting tools etc. which could replace the crude stone objects. In India the occurrence of native copper is very rare and there is a possibility that Indian craftsmen got introduced to this metal by chance reaction between copper bearing minerals like Malachite, Cuprite and Chalcopyrite and charcoal fire. The chemical formula of the copper minerals is given below:

Malachite	-	$CuCO_3.Cu(OH)_2$
Azurite	-	$2CuCO_3.Cu(OH)_2$

Cuprite	-	Cu_2O
Chalcopyrite	-	$Cu.FeS_2$
Hvdrated Blue Vitriol	-	$CuSO_4.5H_2O$

Besides these there are many other minerals bearing copper as chloride etc. The most common mineral of copper found in India is chalcopyrite but others are also found as placer deposits. Chalcopyrite has been reported to occur at Khetri in Rajasthan, Surda, Mosabani and Rakha in District Singhbhum of Bihar, Almorah in U.P., Sikkim and Nepal.

The archaeological survey has indicated that copper was being extracted at Udaipur, Debari, Dilwara, Kedolai, Jhunjhunu, Khetri and Alwar in Rajasthan and Ahmednagar, Daimabad and Ahar in Gujrat and Maharastra region. Singhbhum copper deposits were also being worked in the past and most probably the copper in the Gangetic plains came from here through the river route, whereas the copper objects found in Sindh, Haryana and Rajasthan area came from the ancient mines of Khetri region and Aravali hill deposits. *Fig. 6(a & b)* shows picture of the ancient mining sites located near the modern Surda mine of Singhbhum. Copper working site dating back to 1000 A.D. has been reported by Mohammad (1961) at Agnigundala in Andhra Pradesh. The deposit extends over 3 km and upto 3 km depth and it is surrounded by the entire working starting from mining to pounding stones, washing tanks and melting furnace as well as slag dumps etc.

The first mass scale copper extraction process might have been carried out by carbothermic reduction of Cuprite in a bowl or small shaft furnace because this does not involve the complicated treatment of sulphide minerals. A comparative stepwise flowsheet is given below :

(i) Cu_2O+C (wood charcoal) $\xrightarrow{heat}$ $2Cu+CO$ (Reduction of oxides)

(ii)(a) $CuS.FeS+O_2 \rightarrow CuO + FeS+SO_2 \xrightarrow{O_2} CuO+Fe+SO_2$ (Roasting), and

(iii)(b) $2CuO+2FeO+2C+SiO_2 \rightarrow Cu+2CO+2FeO.SiO_2$ (Reduction).

Thus we see that the production of copper from Chalcopyrite is a two step process involving precise control of the thermochemistry. Moesta and Schlick (1989) and Yazawa (1980) have discussed the thermodynamic limits of the roasting and reduction of copper sulphide in great detail. *Fig. 7* gives the phase diagram for the Cu-Fe-S-O system as calculated by Yazawa (1980). These studies have confirmed that for dead roasting a temperature higher than 850^oC is required and during this process iron acts as sulphur scavenger helping the conversion of CuS into Cu_2O and CuO, and during reduction FeO reacts with SiO_2 to form $2FeO.SiO_2$ (Fayalite) slag which has lowest melting point of 1177^oC. The calculations have also shown that although at 1000^oC copper oxides gets reduced to metal but the slag phase remains solid, and that molten metal separates out only at temperature above 1250^oC. Based on the occurrence of 1.08 to 1.88% iron in the copper objects from Ahar, Chakraborti (1983) and Tripathi (1985) have formed the opinion that copper and iron oxides can be simultaneously reduced easily, and in presence of copper the reduction of iron oxide is possible only at very low pressure of oxygen ($\log PO_2 = 10^{-3}$ atmosphere) normally not possible to attain in the low shaft furnace. Maddin (1982) and his group have conducted some experiments on the ancient reduction technology and they have found that during the reduction of roasted

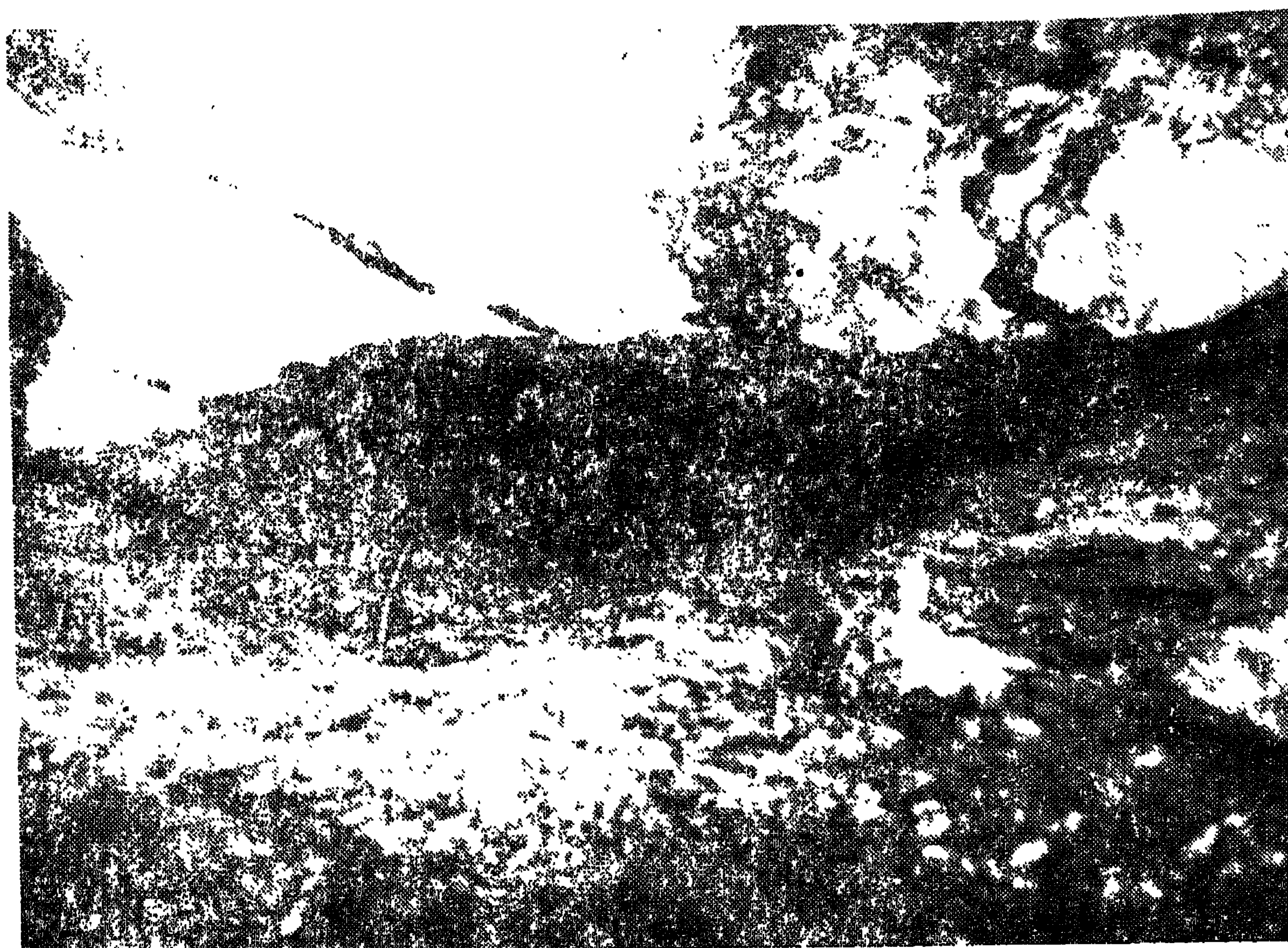




Fig. 6. Photograph showing an ancient copper mining (a) trench, (b) mouth of shaft at Surda Mines, Singhbhum

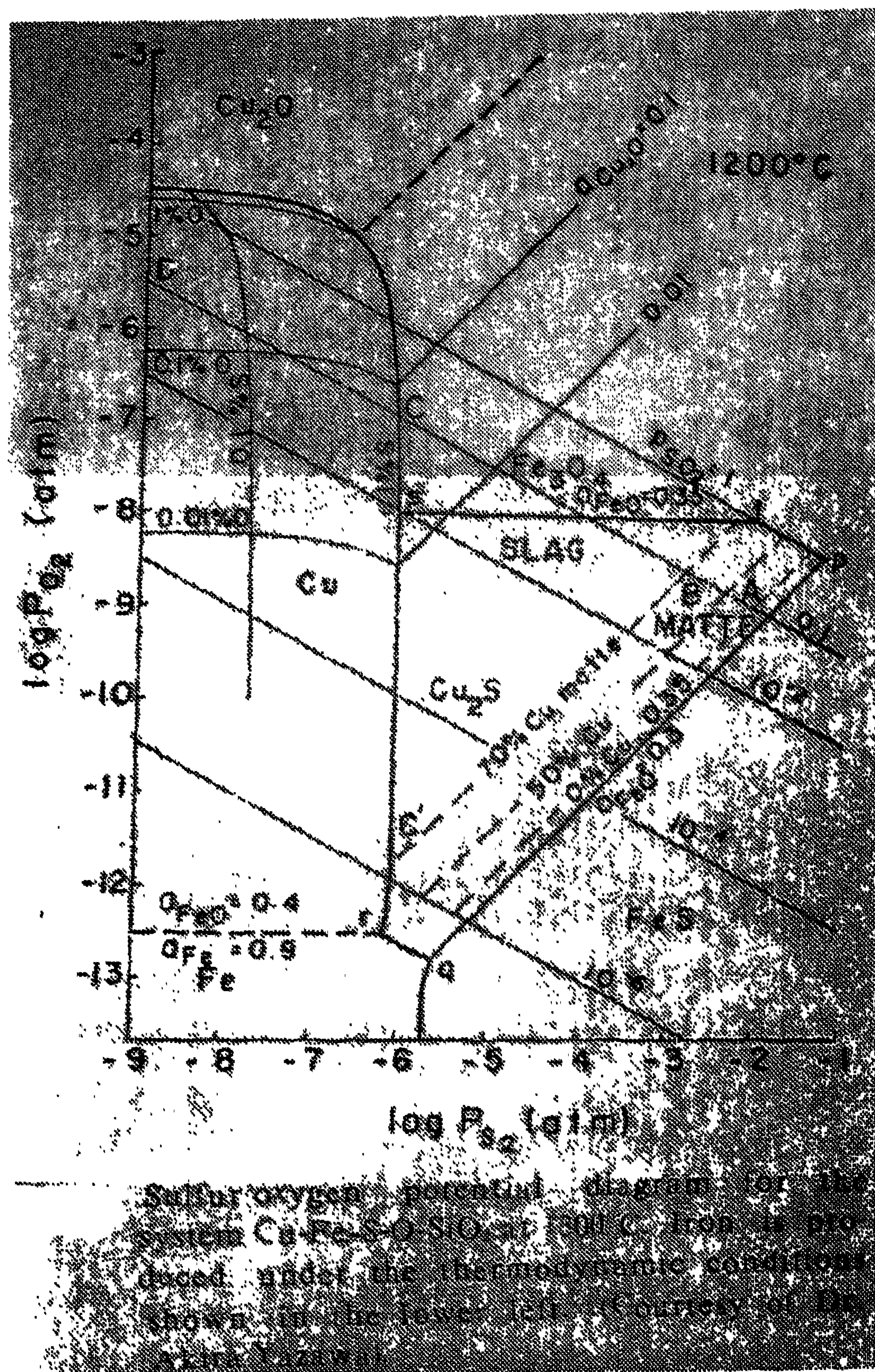


Fig. 7. Cu-Fe-S-O equilibrium diagram (at 1300°C) indicating the instability of metallic iron in presence of CuO, and ultra low oxygen pressure required for its production

chalcopyrite all the iron oxide forms $2FeO.SiO_2$ slag with silica, and they did find some prills of iron embedded in the slag.

The chemical reactions taking place during the production of copper are as given below:

i) Roasting reactions



$$4CuFeS_2 \rightarrow 2Cu_2S + S_2 + 4FeS . \quad ..(1)$$



$$2FeS_2 \rightarrow 2FeS + S_2 \quad ..(2)$$



$$4CuS \rightarrow 2Cu_2S + S_2 \quad ..(3)$$



$$S + O_2 \rightarrow SO_2 \quad ..(4)$$



$$4Cu_2S + FeO \rightarrow Cu_2O + FeO \quad ..(5)$$



$$2FeS + 3O_2 \rightarrow 2FeO + 2SO_2 \quad ..(6)$$

ii) Reduction reactions



$$Cu_2S + 2CuO \rightarrow 6Cu + SO_2 \quad ..(7)$$



$$Cu_2O + C \rightarrow 2Cu + CO \quad ..(8)$$



$$2FeO + SiO_2 \rightarrow 2FeO.SiO_2 \text{ (slag)} \quad ..(9)$$

Percy (1861) and Tylecote (1962) have mentioned that in Sikkim evidence of old copper working has been found and there powdered ore was mixed with cow dung, balled and roasted. Then the roasted ore was melted with charcoal in a shaft furnace to produce copper. At Khetri also similar process was in practice as quoted in Gleaning in Science (1831) and by Anon Brook(1964).

The analysis of copper smelting slag at various sites have been found to contain Fayalite as the major constituent and the slag from Rajghat contained $CaO.SiO_2$ also, besides other impurities like Al_2O_3, MgO, the CuO content of the slag was 1.05 only.

Rasa Ratna Samuccaya has mentioned a number of processes for obtaining pure copper from chalcopyrite by smelting small charges in crucibles as reviewed by Jha (1990). He has conducted detailed experiments on the process of extraction of copper from chalcopyrite following the Ayurvedic route and using Lemon juice as the reductant. In this process after purification (sodhan) of chalcopyrite following the Ayurvedic process the ore mineral was roasted at 750-900^{o}C adding lemon juice during the process. The process of roasting was alternated by tritaturation of the charge. In this process 100 c.c. of lemon juice was added per 100 gm of the ore. During the roasting process Cu and Fe get converted to citrates. ~~The roasted ore~~ was mixed with 25% Borax (flux) and more of lemon juice and the mixture was pressed into 20-30 mm balls. These balls were dried in Sun and then melted in Silimanite lined crucibles at 1250^{o}C. There are four stages of the process of production. On carrying out the melting at 1250^{o}C almost sulphide and gas free copper button separated from the liquid slag was obtained. *Fig. 8* shows the microstructure of the copper button showing dendrites of copper and some inclusions of CuS, CuO and slag.

Another process mentioned in the *Rasa Ratna Samuccaya* is based on the precipitation of Cu from blue, vitriol solution ($CuSO_4$) by the process of cementation.In this process concentrated $CuSO_4$ solution was kept in an iron bowl, where on the surface a copper layer was formed following the reaction given below:



$$CuSO_4 + Fe \rightarrow FeSO_4 + Cu \quad (10)$$

After some time when a thick layer of pure copper particles was deposited on the iron surface the solution was removed and then copper was collected by scrapping it away from the iron surface. This pure copper was carefully washed with water free from (SO_4) and used for the preparation of copper *bhasma.*

(III.2) Thermo-mechanical Treatment of Copper

Copper, a brick red coloured metal has a melting point of 1083^{o}C and it is very ductile in nature. This can be easily cold or hot worked to give any shape like rod, plate, wire and sheet etc. Hence, it has been extensively used in the past for the

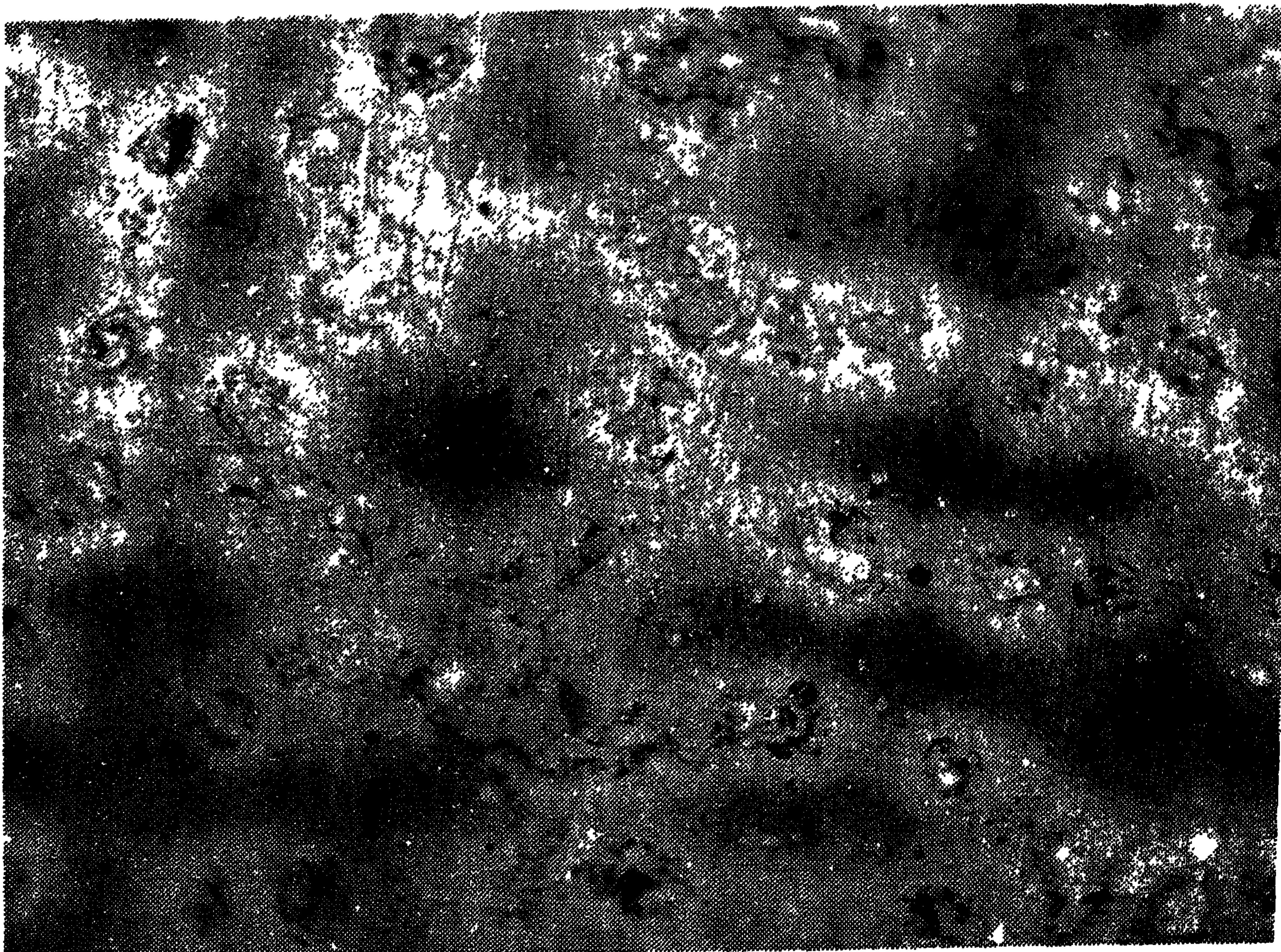


Fig. 8. Microstructure of copper button produced by the Ayurvedic method showing dendrites of copper and presence of CuS, CuO and slag inclusions, Mag. x 100

manufacture of domestic utensils, jewellery as well as for covering the wooden surface and engraving it for decoration and preservation of wood pannelling. The work hardening effect can be easily removed by annealing at 700-800^{o}C in cowdung fire to produce metal having stressfree recrystalised grain having high ductility. The archaeological evidences have shown that this metal was shaped into various objects by casting into stone and clay moulds, hot and cold forging and soldering or rivetting to join two metal pieces. The ancient craftsmen had a flare to produce beautiful designs on the copper objects by embossing, engraving and gem setting. Beautiful objects having carvings inlayed with Gold and Silver wire and hot enamelled have been also found in latter stages. Copper being soft metal the sharp edge of the hunting tools and war weapons were hardened by cold working till the technology of production of bronze and Cu-As alloys were developed, which were much harder than the cold worked copper. On polishing the surface of copper could be given a highly shining polished finish which was being used as a mirror in the royal families. The Gold coating of copper objects by the process of amalgamation was also in the practice to produce various decorative cheap articles made from copper but having a golden finish.

(IV) Iron and Steel

The discovery of iron and its technological development on the Indian subcontinent has raised many questions because of the lack of archaeological proof

dating back to those existing at Lustrian in Iran and other centres of ancient civilization. There is a total absence of iron objects at the Harappa and Mohenjodaro sites but the recent excavations at Lothal,Ahar(1300 B.C),Gufkral (1300 B.C.),Atranjikhera (1025 B.C.),Tadkanhalli(1000 + 150 B.C.) Hallur (1000 to 900 B.C.) and Khairadih (1000 + 100 B.C.) have pushed back the beginning of the iron age to the same period as those outside India. *Fig. 9* shows the ^{14}C dating of the iron objects found at some of the important excavation sites of India and its shows a definite trend of simultaneous development and appearance of this metal all over India. *Table 2* gives the chronology of development of iron tools and other objects during the early, middle and later stages of the development of iron age in the country. This table clearly shows a gradual widely spread development of the use of iron which is possible only under the conditions where the knowledge of the use of these artifacts is lacking. This indicates that in all probability the iron technology in India is independent of the copper technology and it might have been developed even before copper.

This hypothesis is further supported by the nature of the deposit of the mineral of the two metals, and comparatively easy method of obtaining iron from the oxide

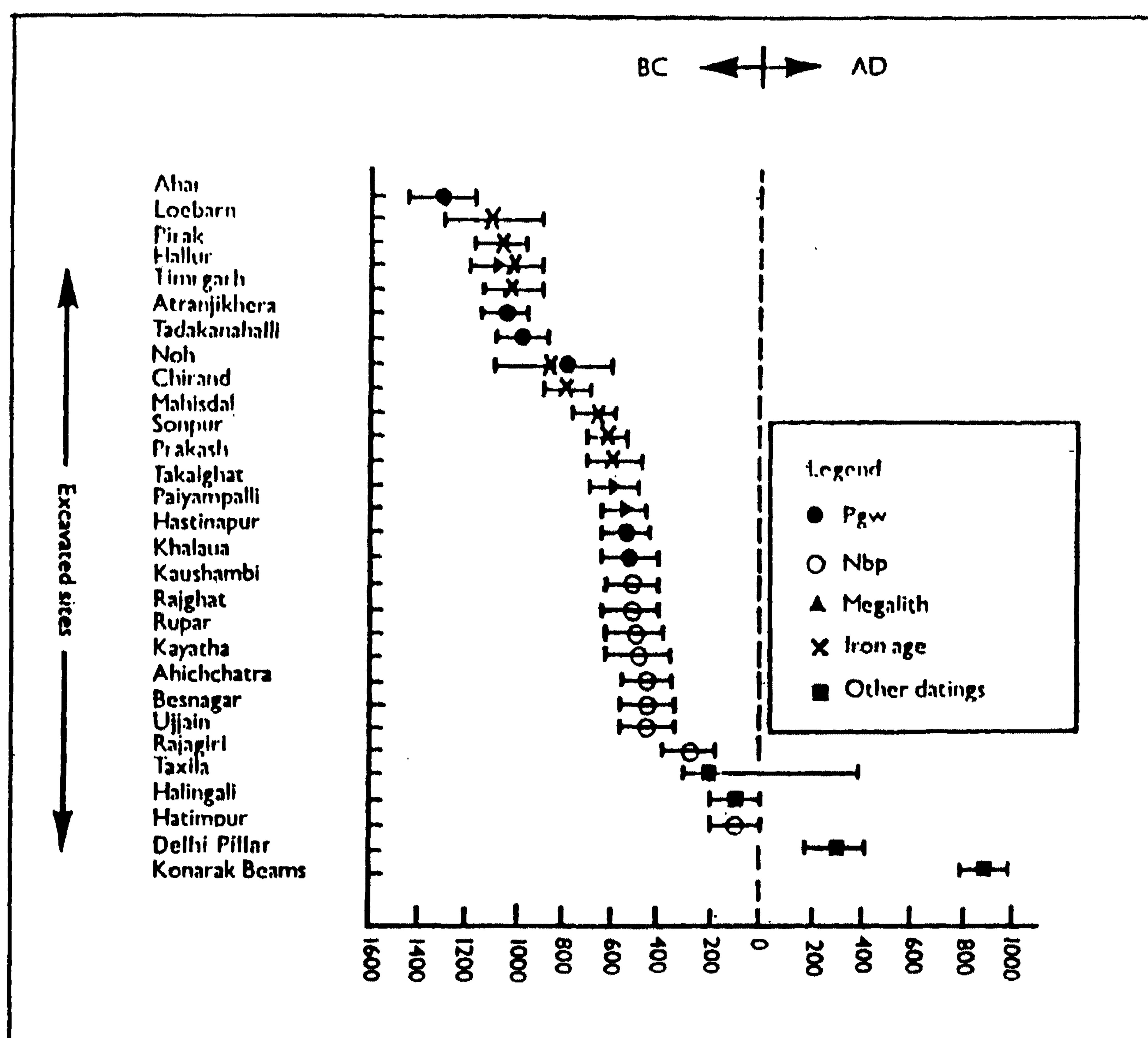


Fig. 9. ^{14}C dating of some of the iron objects found at different archaeological sites in Indian subcontinent

Table 2 — Various tools and implements appearing at the three stages of iron technology growth

Tool Type	Name of Tool	Early Stage	Middle Stage	Late Stage
Hunting Tools				
	Spear heads	*	*	*
	Arrow heads	*	*	*
	Points	*	#	#
	Socketed tangs	*	#	#
	Blades	*	*	#
	Spear lances	#	*	#
	Dagger	#	*	*
	Sword	#	*	*
	Elephant goad	@	*	*
	Lances	@	@	*
	Armour	@	@	*
	Helmet	@	@	*
	Horse bits	@	@	*
	Caltrop	@	@	*
Agricultural Tools				
	Axes	*	*	*
	Sickles	*	*	*
	Spade	@	*	#
	Ploughshare	@	*	#
	Hoe	@	*	*
	Chisel	@	*	*
	Pick	@	#	*
Household Objects				
	Knives	*	*	*
	Tongs	*	#	#
	Discs	@	*	#
	Rings	@	*	#
	Spoons	@	*	*
	Sieve	@	@	*

Contd.

Contd(Table 2)

Tool Type	Name of Tool	Early Stage	Middle Stage	Late Stage
	Cauldron	@	@	*
	Bowls	@	@	*
	Dishes	@	@	*
Building Materials				
	Rods	*	#	#
	Pins	*	#	#
	Nails	*	*	*
	Clamps	*	*	*
	Pipes	@	*	#
	Sockets	@	*	#
	Plumb bob	@	*	#
	Chains	@	*	*
	Door hooks	@	*	#
	Door handle	@	@	*
	Hinges	@	@	*
	Spikes	@	@	*
	Tweezers	@	@	*
	Anvils	@	@	*
	Hammers	@	@	*
	Scissors	@	@	*
	Saw	@	@	*

* indicates definite existence;

@ indicated non-existence;

indicates that confirmed data is not available.

ore than copper from the sulphide ores. In India while iron ore Fe_2O_3 and Fe_3O_4 are occurring as surface deposits embedded in the Quartz and Dolomite minerals below the gound level. This aspect of the discovery and development of iron technology has been discussed in detail by Prakash, B. (1990) and from this view point the earlier attempts of correlating the discovery of iron to P.G.W. and N.B.P. in the Northern India seems to be inaccurate, although iron implements appear along with these potteries at many sites.

The survey of ancient literature has provided ample proof that iron and steel making technology and their difference has been known in the Vedic period (vide reference on *Ṛgveda* and *Yajurveda*) and may be even earlier. These evidences also support the hypothesis of Sharma R.S. that Aryans were the original inhabitants of

India and this also supports the use of iron both by Aryans and Dravidians even in the pre-historic period. As cited earlier Indians of the Vedic period were using steam powered transport vehicles and they were capable of producing many types of war weapons and agricultural tools which is possible only by the use of iron and steel.Prakash and Tripathi(1986),and Kulkarni(1989)have published a detailed review on this metal and listed chemical composition of many of the iron objects. These objects have carbon content of 0.03 to 1.3% and they are basically Fe-C alloys. The *Suśruta Saṃhitā* has mentioned the method of fabrication (700 B.C.) of more than 100 surgical tools made of Fe-C alloys and the process of heat treatment to obtain razor sharp edge capable of splitting hair into two halves longitudinally.

Fig. 10 gives the sketch of some of these tools prepared on the basis of their description in the text. *Fig. 11* shows the collection of iron swords and daggers etc. collected from the excavations at Tinnevelley dating back to 400 + 100 B.C., and *Fig. 12* and *13* show various iron objects found at Atranjikhera dating back to 1200-1000 B.C.

Some of the massive iron objects manufactured in India in the Christian era have no parallel in the world, such as the famous Iron Pillar at Delhi (4th century A.D.) weighing 6000 kg, Iron Pillar at Dhar (12th century A.D.), weighing 7000 kg, 29 iron beams at Konark in Orissa (9th century A.D.), of which the longest one measures 11000 mm in length and 175 by 197 mm in cross section weighing about 3000 kg, the iron trident at the temple of Achaleshwar on mount Abu, the iron pillar at Kondachari and the iron trident at the temple of Tanginath near Bishunpur in Bihar. Some of these are shown in *Fig. Nos. 14 to 18.* The massivity of these objects and their high corrosion resistance have kept the modern metallurgists and technologists wondering about the manufacturing and processing details as well as the cause of their such high corrosion resistance.

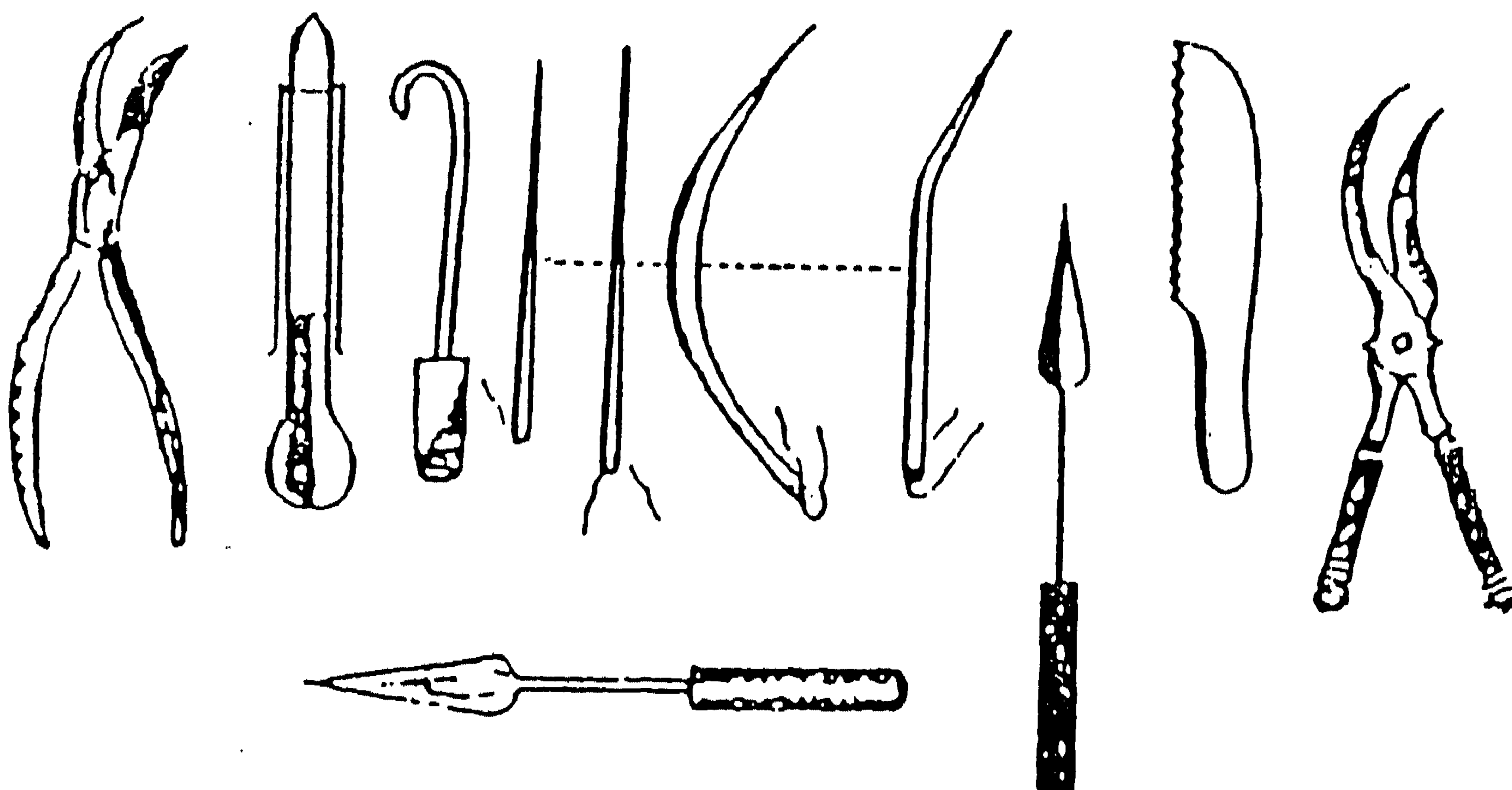


Fig. 10. Sketch shows some of the surgical tools designed by Suśruta

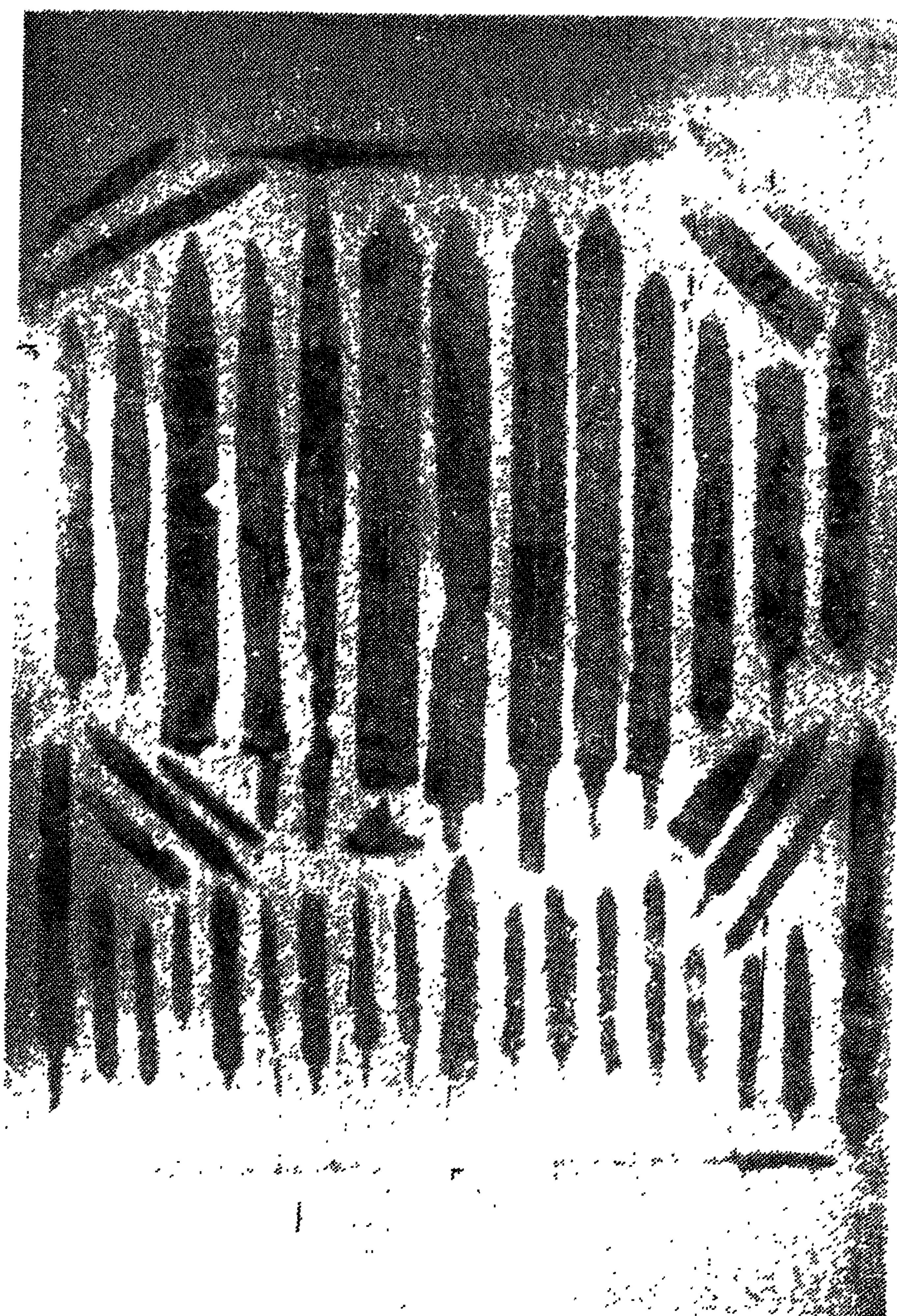
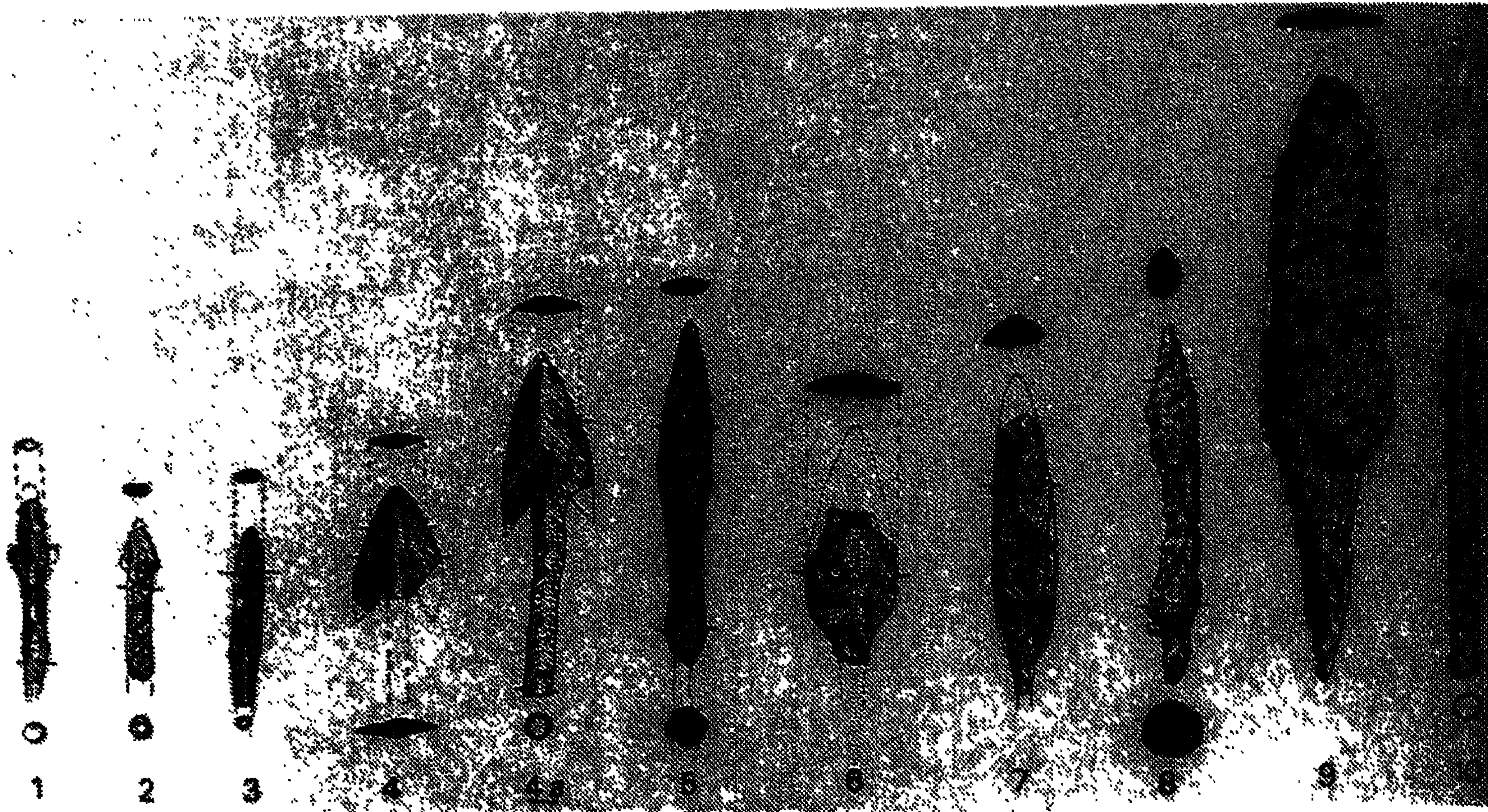


Fig. 11. This photograph shows some of the Iron swords and daggers found at Tinnevelley (400 B.C.)

(IV.1) Iron Minerals and Smelting Technology

Iron occurs in nature mostly as Fe_2O_3(Hematite) and Fe_3O_4 (Magnetite) and some Pyrite deposits (FeS) have also been known. Besides this, in some parts of the world Meteoric Iron has also been found and used for the early war weapons. Iron of Meteoric origin is easily distinguished by its high Nickel content.

India has been bestowed with one of the largest and richest deposits of Hematite, Magnetite and their hydrated forms like limonite etc. and these deposits are spread all over India. These deposits have been worked all over India to produce sponge iron or wrought iron using variety of furnaces and archaeological remains of a number of furnaces have been found at Nalanda, Naikund, Khairadih, Ujjain and many other sites. *Fig. 19* shows a sketch of the reconstructed furnace dating back to 700 B.C. As can be seen this furnace has been constructed from prefabricated refractory clay blocks or bricks, whereas the furnaces used in Western Asia and Europe in the same period were either made by digging a hole in the earth or by arranging stone pieces to give the desired shape. These furnaces were generally used only once and then discarded after taking out the hot bloom. That is the



Iron Weapons : Period III: 1-8, Arrow heads; Spearhead; 10. shaft 1/2
Fig. 12. Some of the iron objects excavated at Atranjikhera (~1000 + 200 B.C.)



Iron Tools and Implements: Period III: 1-3, clamps; 4-6, chisels; 7-8 , Bars; 9-10, Borers; 11, Needle 1/2
Fig. 13. Some of the iron tools and objects found at Atranjikhera (~1000 + 200 B.C.)

probable reason for the occurrence of a cluster of furnace remains at the sites excavated in the West, whereas in India the furnaces seem to be reused after relining and repair with refractory clay. Buchanan (1807), Hadfield (1912) and Verier



Fig. 14. Iron Pillar at Delhi and its microstructure at the bottom of the pillar

(1942) have given detailed description of the working of a large variety of iron smelting furnaces and the steel industry prevailing in the country during 17th to 19th century. Ray (1956), Joshi (1970), Banerjee (1965), Krishnan (1955), Prakash B. (1983) Chatterjee and Altekar (1973), Bhardwaj (1982) and many others have surveyed the available information and published excellent reviews and books on the subjects.

The smelting of iron in the past was done only by a special group (caste) of persons in each tribe and they all worshipped the God 'Asura'. This may be because in the early days of the discovery of this metal it was being used only to make war weapons and hunting tools (refer *Table* 2), and the general public being peace-loving the handling of this metal was considered the work of 'Asura' who gave devilish power in the hands of man. The belief of the ancient iron smelters in lord 'Asura' has been so strong that his image was put even in the 'Maṇḍala' of

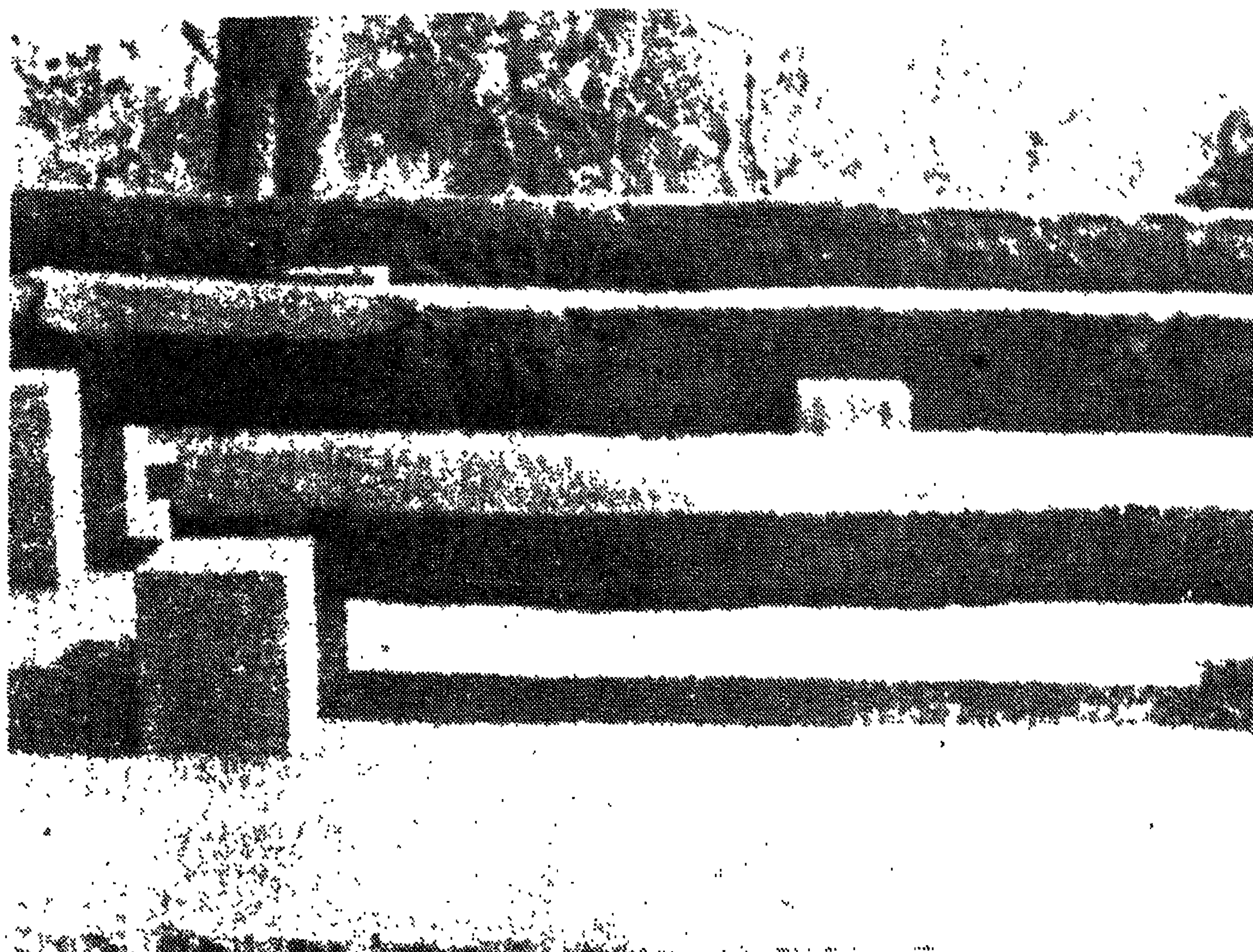


Fig. 15. Dhar Iron Pillar broken into three pieces. The change from square to octagonal section at the top can be seen

ancient iron making in Japan (Buddhist period) as can be seen from *Fig. 20* which shows the painting of 'Kāla Bhairava' and 'Asura' working for the iron smiths (Prakash, B. 1990). In Bihar, Orissa and Eastern part of Karnataka the iron smelting was carried out, by these 'Asuras' and in Central India by 'Āgārias'. Verier (1942) and Joshi (1970) have written in great detail about the 'Āgāria' tribe and their iron smelting practice spread through the central province, Rewa, Udaipur, Sirguja, Ranchi and Koraput etc. *Fig. 21* shows the region of India in which according to Verier (1942) Āgārias were smelting iron. In some places they are confused with 'Lohārs' or 'Lohārins'(blacksmiths) but as Verier (1942) has described, while Āgārias smelted the iron ore to produce wrought iron blooms 'Lohars' shaped the rough iron to manufacture various tools and objects and carried out suitable heat treatment operations. In the year 1982 Prakash and Igaki (1984) surveyed the district of Bastar where iron making by Mundia tribe was mentioned and they could locate one furnace in the interior of the jungles of 'Bastar; at Loharpara as reported in their paper.

At Bishunpur on the road between Lohadāga and Netārhat (near the Bihar, Madhya Pradesh border) Sharma, M. has located the site where iron smelting was being done earlier, and his group has got it revived under a rural development plan 'Vikas Bharati'. There the smelting is done by Birjias and Lohars both belonging to the Asur tribe. A detailed report on this revived iron smelting has been published by Prasad, K.K. (1990) and his group. For recent survey, vide Sahasratudheya et al (1993) of P.P.S.T. Foundation.

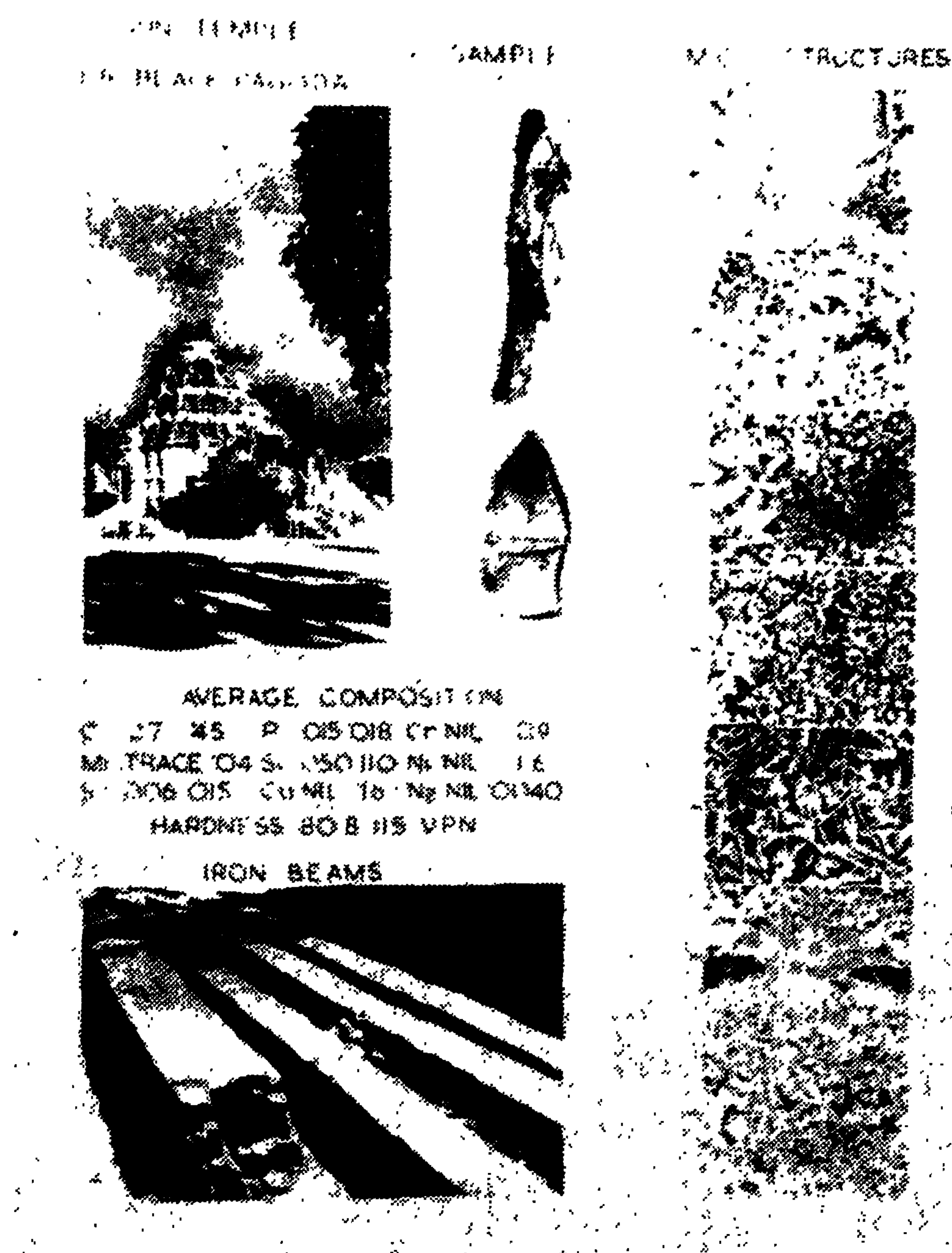


Fig. 16. Iron beams (12 century A.D.) lying at the Sun temple of Konark

The ancient iron making practice consisted of the following operations and each one of them was performed under the strict supervision of the oldman or master craftsman of the tribe. The operation of the furnace was considered to be a sacred ritual and they prayed to the tribal God 'Asur' for the success of the smelting. Many of the 'Mantras' and verses have been preserved as folk songs and these have been vividly described by Joshi (1970). The secret of iron smelting process was very religiously guarded and passed on only to the younger generation of the family or tribe. Women had active role to play in the process and certain specific jobs were to be done only by them. In *Rasa Ratna Samuccaya* a full chapter has been devoted to describe the characteristic features of the female helper 'Kalini' and her duties during such religious rituals.

The whole operation of the furnace can be divided into five parts

i. Collection and preparation of the raw-material

ii. Making of the furnace and its dressing

iii. Making of air bellows and their fitting

iv. Ignition of the furnace and its operation

v. Handling of the sponge iron.

Following is a short account of the furnace operation :



Fig. 17. Iron Pillar at Kondacheri

(i) *Collection and preparation of the raw-material*: Iron ore - mostly weathered soft Heamatite ore was used but in some regions like in Assam and South India magnetite sand has also been used for the extraction of iron. The operation was generally carried out in the vicinity of the ore deposit or in the nearby forest where suitable charcoal could be made from the wood. It was the duty of the experienced men to locate suitable deposit of the ore and dig it out after performing the puja. Women used the help in transporting the ore and breaking it into pea size (3-5mm). In Mandla before starting for the collection of the ore a '*mantra*' was recited for the success.

The translation of this '*mantra*' is as follows:

"Go and seek *Lohār Mātā*, God lead on bed, trusting thee I follow"

Evidences have been found of mining even at a depth of more than 10m.

Charcoal – Charcoal was prepared from wood like Irool (Xylia dolaberiformis) Teak, Babul (Acacia arbica), Sal (Shorea rubusta), Bamboo (Caleotropis gigantica) etc. yielding dense and heavy charcoal. It was prepared by cutting the dried branches and trees and burning them into an open heap or inside a pit and when the wood was charred the fire was extinguished by covering the burning wood with



Fig. 18. Iron Trident (Trishul) at Tanginath temple near Netarhat (M.P.)

green leaves and twigs, and sprinkling water on it. After the fire has completely died out the charcoal was collected and used for smelting. In the latter period Beehive type of firing chambers were introduced for controlled charring of the wood.

Flux – No evidence of the use of lime stone or lime as flux has been found except the SiO_2 and CaO present in the ore and the charcoal ash. Some times SiO_2 has been added to the charge to make the fluid $2FeO\text{-}SiO_2$ slag. Ayurvedic charges for '*Satvapatan*' i.e. extraction of metals from minerals have used Borax as flux. The first use of lime as flux in iron smelting has been found at Ujjain (M.P.) and Bairut (Rajasthan), where this technology went through a faster growth.

(ii) *The iron making furnaces and its dressing*: Variety of small and large furnaces have been described by Joshi (1970), Banerjee (1965), Krishnan(1955), Prakash(1983), Chatterjee et al. (1973) and Ghosh (1964) and many others, which have been in operation during the 17th and the 18th century in various parts of the country. These furnaces were called *Bhaṭṭi*, *Kothi* or *Koṣthi* and they were made from locally available clay, and at many places internally lined with natural china clay or a refractory mixture generally used for crucible manufacture. More details

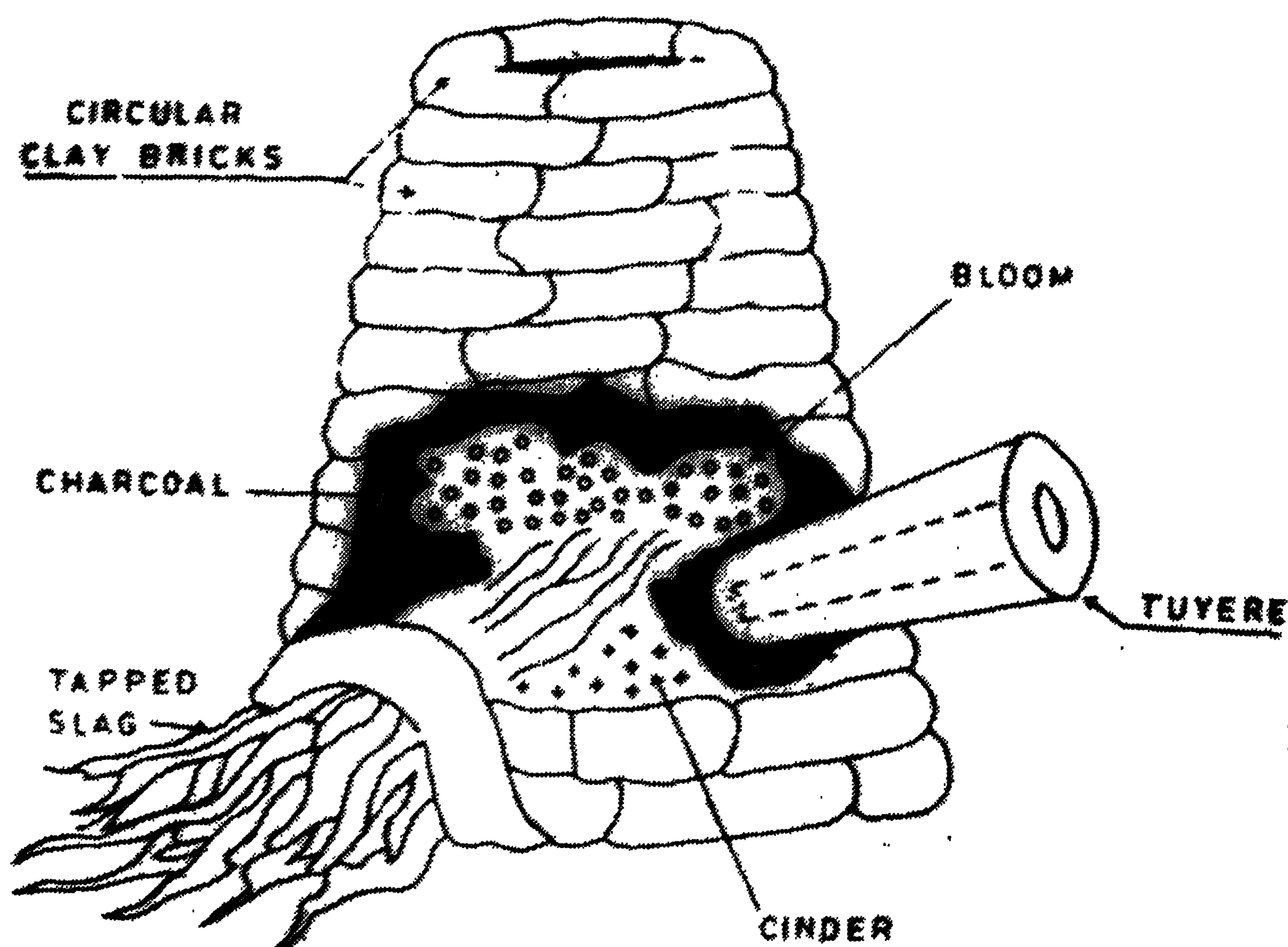


Fig. 19. Iron smelting furnace found at Naikund (700 B.C.)

about this mixture will be given later. These furnaces were either made below the ground level or on the sloping face of a hillock or above the ground level.

They can be classified into three main groups :

(a) the furnaces of South India having bowl shaped hearth and conical shaft. The furnace was made generally below ground level. *Fig.22* shows a picture of a furnace from Salem which has been made above the ground level.

From the study of this furnace it seems that a former or inner mould made of read or other thin wood was being used to give the desired contours to the interior of the furnace.

(b) the second type was cylindrical furnace of Madhya Pradesh, where the bloom was removed from the top,

(c) *Kothi* type furnace of Bhopal and Ujjain zone were much larger as compared to the others and had square or rectangular cross- section.

Figs. 23 to 25 show photographs of different types of furnaces which were in operation during 17th to 19th century. All these furnaces had two holes at the bottom, one for introducing the blast and the other for removing the molten slag. Generally a slanting platform of bamboo, lined with mud, was prepared at the mouth of the furnace to preheat the charge and to push it inside the furnace. A picture of a bowl type furnace which the author studied in 1981 is found at *Lohārpārā* in the district of Bastar. The line diagram shown in *Fig.26* gives the details of this furnace made in one of the walls of a pit below the ground level. *Fig. 27* shows a line diagram of a twin hearth furnace described by Buchanan which was capable of

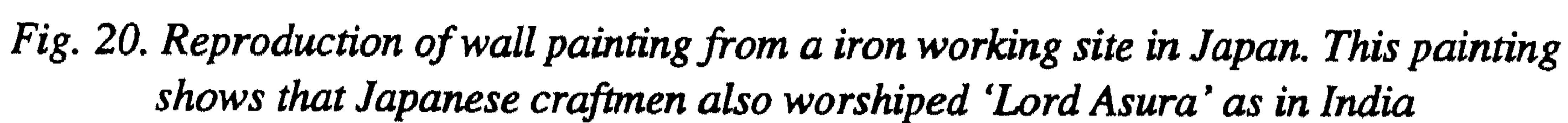


Fig. 20. Reproduction of wall painting from a iron working site in Japan. This painting shows that Japanese craftmen also worshiped 'Lord Asura' as in India

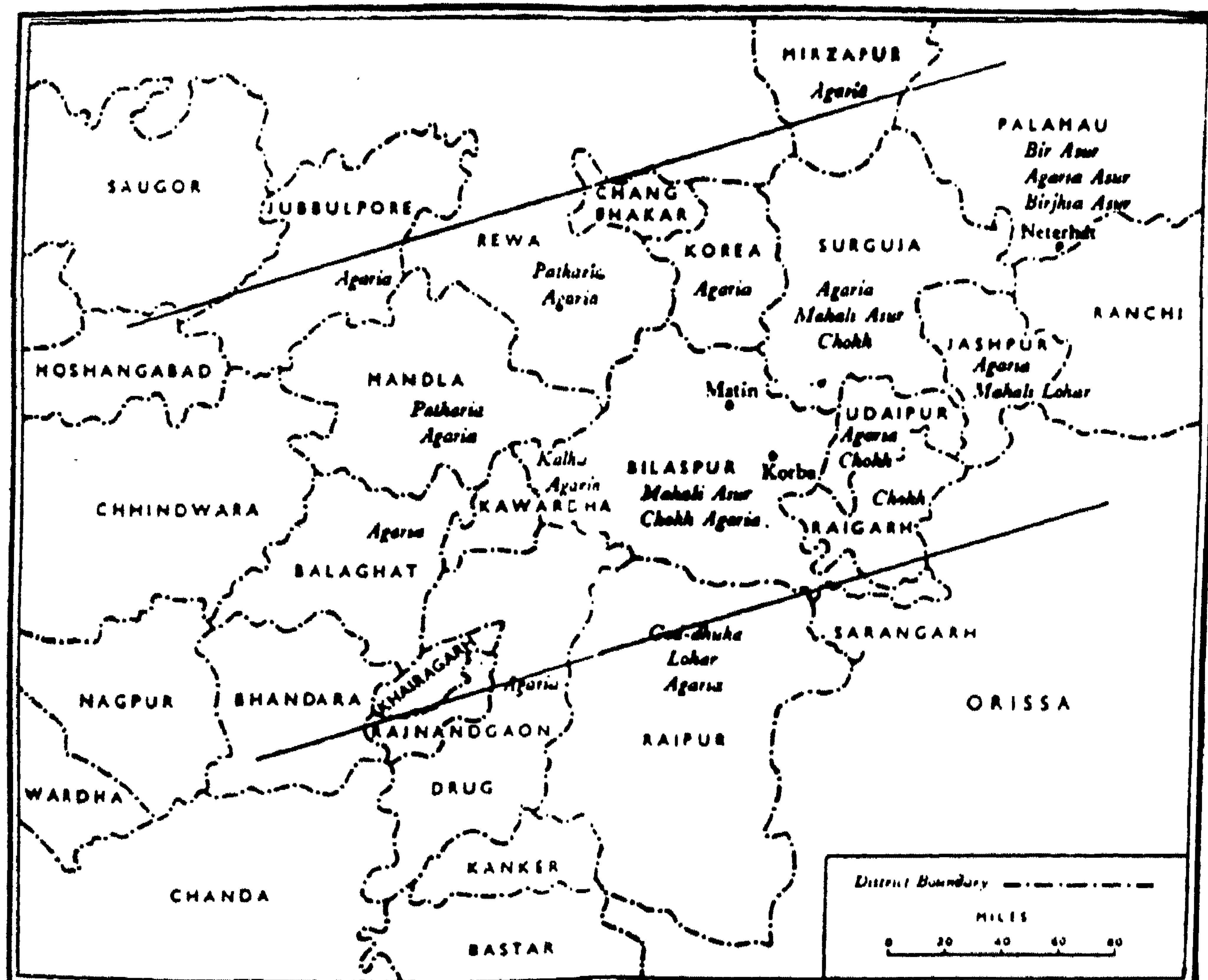




Fig. 21. Map of Central India showing the region in which 'Āgārias' were active in the production of iron. Agarias carrying iron ore for smelting



Fig. 22. Iron smelting furnace from Salem, showing the use of former made of reed to make the inner contour of the furnace



Fig. 23. Artists impression of the operation of iron smelting furnace using two men to operate a pair of 'Bhathi'



Fig. 24. Primitive blast furnace of Nagpur region

producing 250 kg of iron per day in the Malabar area. The furnace was fitted with more than one pair of bellows, and peep holes were suitably located to monitor the temperature inside the furnace. Mahamud(1988) has described a furnace from Assam which is asymmetrical in design as shown in *Fig.28.* One of the walls of this furnace is slanting and this was probably designed to smelt Magnetite sand. *Table 3* gives the detailed dimensions of most of these furnaces as available in the literature.

Table 4 gives technical analysis of the design features as compared to those of a modern Indian furnace producing more than 1000 tonnes of iron per day. These design features have been calculated on the basis of the design principles of the modern furnaces as discussed by Bashforth(1973).

A study of *Table 4* shows that the ancient furnaces listed in *Table 3* were not merely dug out holes or shafts built above the ground level but they were made



Fig. 25. Photograph of the iron smelting furnace found at Lohārpārā in Bastar

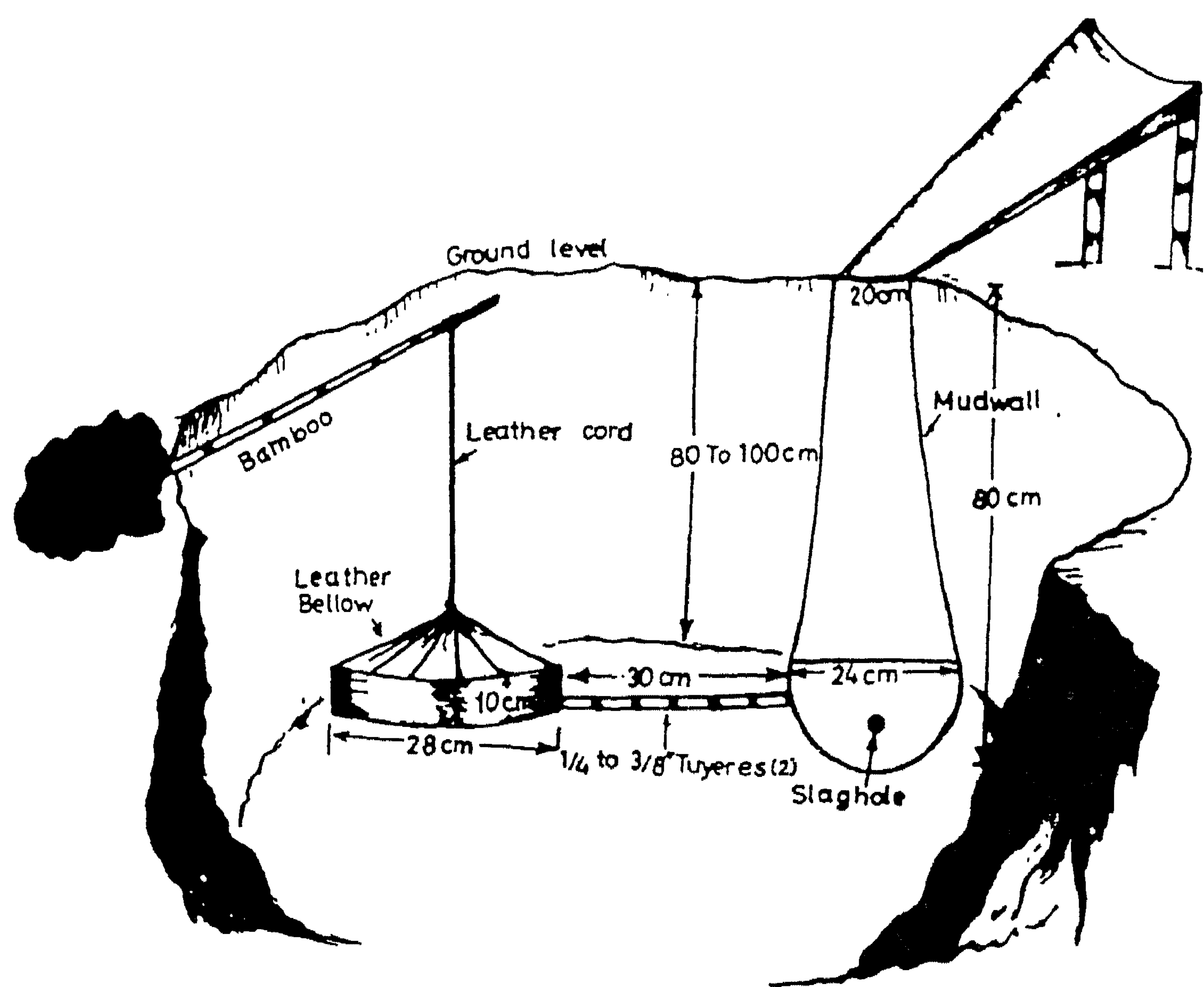


Fig. 26. Line diagram of the Bastar furnace

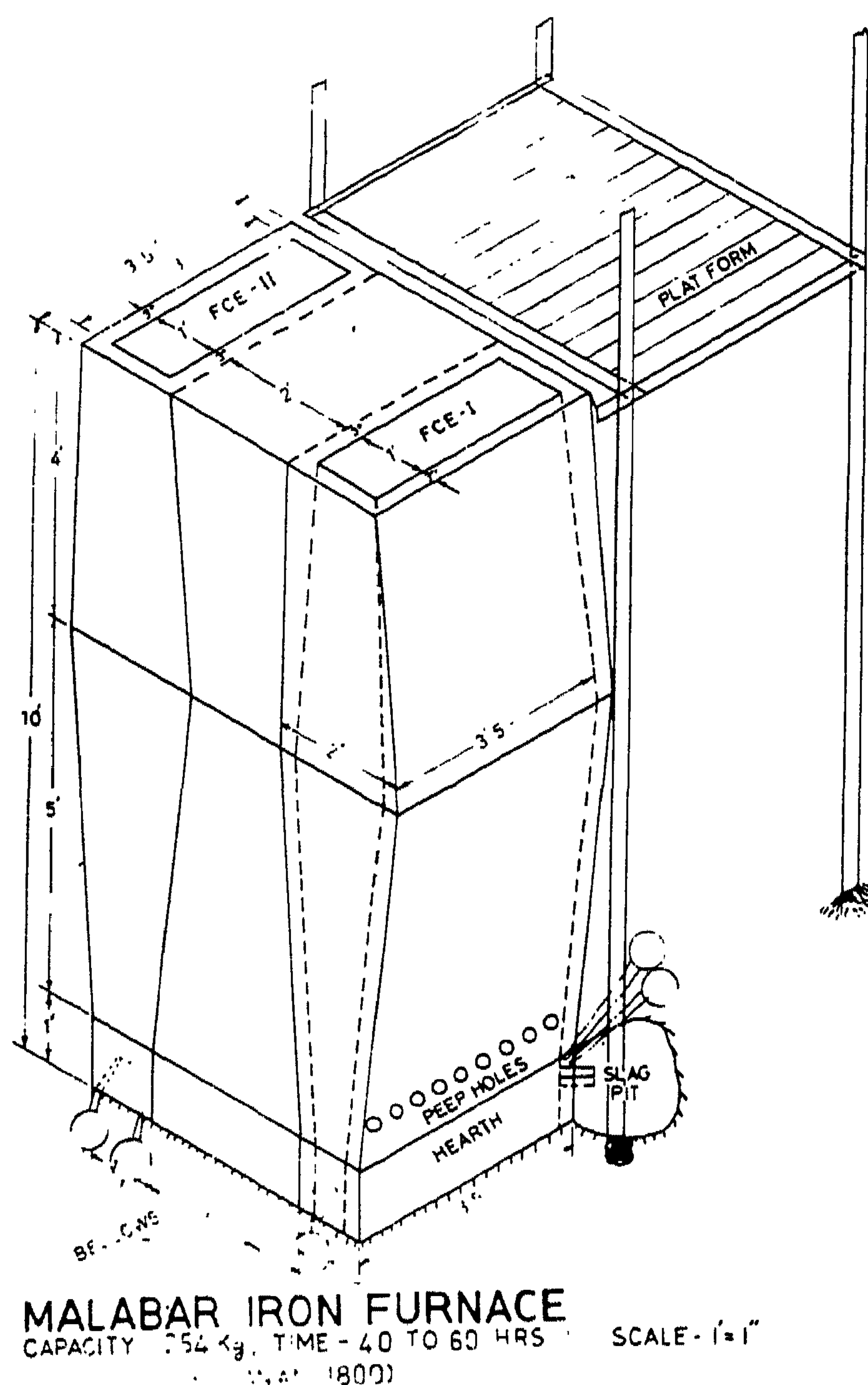
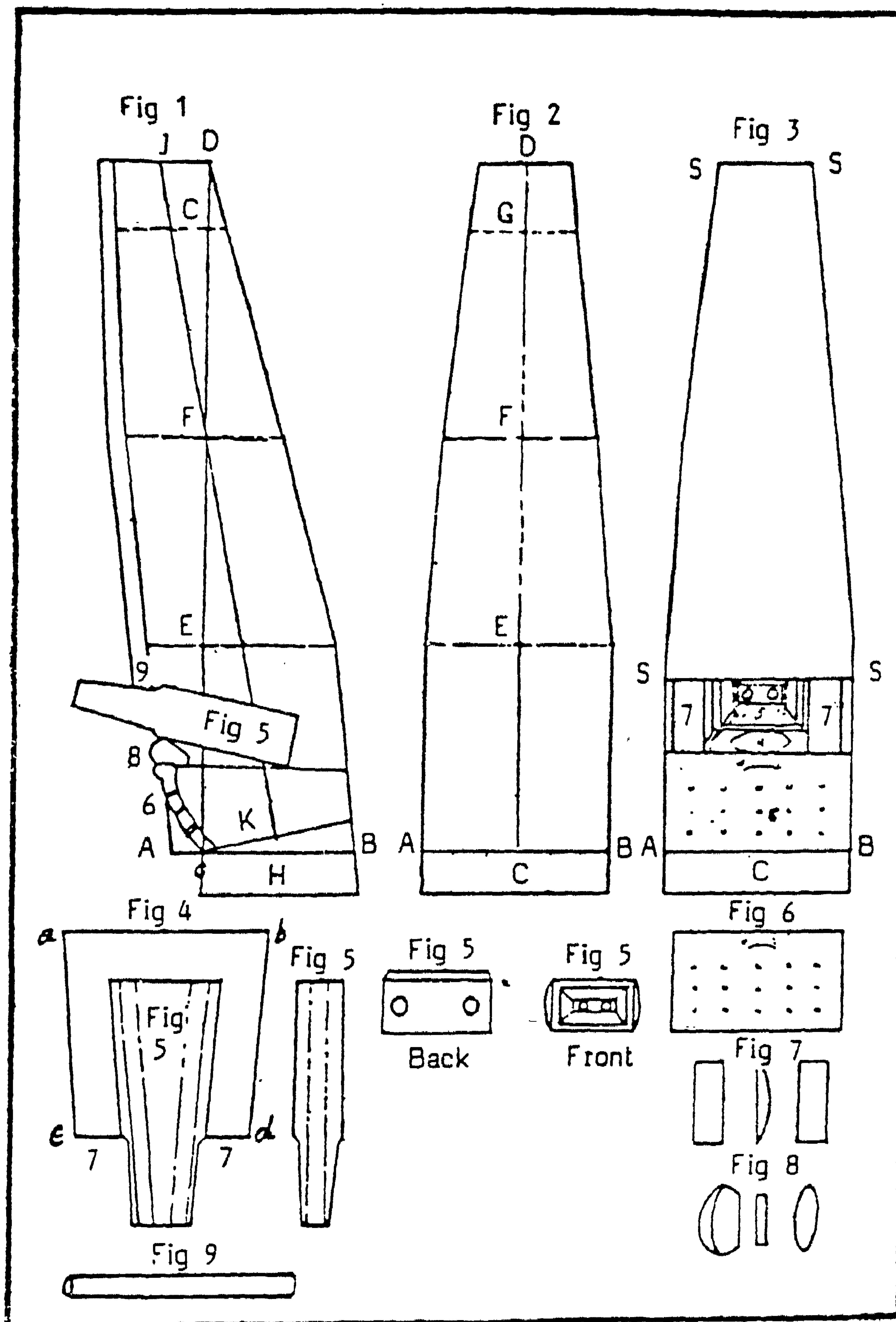


Fig. 27. Line diagram of the twin shaft furnace from Malabar (as described by Buchanan)

based on certain design parameters and principles although they have been of different shapes, sizes and from different parts of the country, and these design principles are very similar to those followed in the design of modern furnaces. For example the throat to bosh diameter (d:D) ratio was 0.28 to 5 in almost all the ancient furnaces while the modern furnace has a value of 0.7 to 0.77. The maximum diameter at the bosh or tuyere level determines the combustion rate of fuel in the furnace and the d:D ratio takes care of the thermal as well as reduction expansion of the ore. The difference between the values of ancient and the modern furnace may be due to the change in the nature of the charge i.e. ore, etc. and the use of coke instead of charcoal in the modern furnace. In a similar manner the stack angle and H/D/2 ratio also shows a good similarity with those for the modern furnace. The useful volume of the furnace has changed from furnace to furnace and for the larger furnace (1000 tonnes) it is 760 m^3, but there is a good agreement on the volume of the furnace chamber (cm^3) required per kg of iron produced by the direct reduction technique.

This value decreases to 358 cm^3 in the case of the modern furnace because of the indirect reduction promoted in the stack and also higher temperature and productivity attained in this furnace. The decreased size of the mouth of the furnaces indicate that the ancient craftsmen were conscious of the importance of gas-solid contact time and the control of gas velocity inside the furnace. All these design



Geometrical Outline of the Furnace.

Fig. 28. Iron smelting furnace having asymetrical shaft (as described by Mahamud. Figure numbers indicated in this picture refer to various parts and their position in the main furnace

features must have been achieved after keen observation and experience of operating large number of furnaces. It is important to note that Indian smelters had achieved these optimised conditions with time inspite of their ignorance of modern physico-chemical principles and the changes occurring in the raw material during reduction.

Table 3 — Technical details of ancient iron furnaces

Sl No.	Location of furnace	Shape	Cross section		Height cm kg	No. of bellow	Capa-city kg	Remarks
		Max cm.	Mouth cm.	bellow				
1.	Madhya Pradesh	Circular	O.D.107 I.D. 43	O.D.56 I.D. 12	137	two	16	Made above ground level
2.	Madhya Pradesh	Rectangular	122 × 76	-	122	four	214	Two furnaces made into a pit of 122 × 305 × 91 cm smelted 380 kg of ore in 3 hrs.made from clay bricks
3.	Nagpur	Square	56 × 56	51 ö 25	92 to 122	two	5	-
4.	Rajdoha	Circular	O.D.107 I.D. 46	O.D. 56 I.D. 13	132	two	18	One heat took 6 hrs. and consumed 80 kg of charcoal
5.	Nalanda Valley	Rectangular	56 × 81	51 × 25	90 to 122	two	5	Charge consisted of 25 kg ore, 25 kg charcoal
6.	Salem	Circular	61	31	90 to 153	two	-	A chimney was fitted over the mouth as shown in Fig.
7.	Mandla	Circular	O.D. 78	O.D. 16	76	-	-	-
8.	Chiglabecha (Koraput)	Circular	I.D. 30	I.D. 15	95	two	-	Hearth of furnace below ground level
9.	Jiragora (Koraput)	Circular	I.D. 25	I.D. 7.5	57.5	two	-	Below ground level
10.	Kamarjoda (Joda, Bihar)	Circular	I.D. 30	I.D. 7.5	67.5	two	-	Above ground level

(Contd.)

(Contd. Table 3)

Sl No.	Location of furnace	Shape Max cm.	Cross section Mouth cm.	Cross section bellow	Heigh t cm kg	No. of bellow	Capa-city kg	Remarks
11.	Bastar	Circular	I.D. 24	I.D. 20	80	two	-	Furnace made below ground level in one face of a square pit 200 X 200 Cm.

During the year 1990 the author had a chance to witness the construction and operation of the ancient reduction furnace at Bishunpur where '*Vikās Bhārti*' was trying to get this process revived as a rural technology. The two old men of 'Birjia' tribe who had seen the operation of iron smelting furnace in their younger days were persuaded to make a furnace and try to revive the technology. The remains of a number of furnaces has been found at Bishunpur, and these furnaces are supposed to be working 50 to 100 years before. *Fig.29* shows the line diagram of the furnace constructed at the '*Vikās Bhārti Centre*' with the twin bellows (*Bhāṭhi*) in position. The furnace has 500 mm internal diameter at the bottom and 150 mm at the top and its height is 800 mm. Its 150 mm thick wall was made from a locally available clay and it was allowed to dry for few days. The shrinkage occurring during drying was patched-up by pressing the clay and applying a fresh coating.

After about a week's time when the clay wall was still moist the front opening of about 300 mm width and 200 mm height was cut open as shown in the figure. This opening was made for preparing the bottom of the furnace, fixing of the clay tuyere pipe and removing the molten slag. The top diameter was measured by old craftsman using a piece of stick and then the excess clay was scrapped away. The taper and bottom diameter of the furnace was checked by dropping a wet clay ball from the top inner edge and then measuring the distance between the centre of the ball mark and the wall. The process was repeated several times all round the circumference of the top inner edge. After correcting the furnace shape and size the inner wall was coated with a locally available non shrinking refractory clay. The bottom of the furnace was made from a mixture of charcoal powder and the mud clay to have a taper towards the opening. Inside the bottom opening a clay pipe having shape like a trumpet with about 50-60 mm diameter at the larger end and 20-25 mm at the smaller end was fixed as shown in the figure and then the mouth was sealed with the clay-charcoal powder mixture. The bamboo pipe of the two air bellows or foot operated *Bhāṭhi* were fixed at the mouth of the clay trumpet as shown in *Fig.29*. Finally the furnace was dried by kindling a fire inside it and slowly raising the temperature to bake the furnace. Now the furnace was ready for operation.

(iii) *Design of the Air Bellow (Bhāṭhi)*: The air to the furnace was provided by a pair of small bellows made of goat or buffalo skin and connected to the furnace

Table 4 — Technical analysis of the design of Ancient and Modern furnace(calculated from the data given in Table-3)

Sl.No	Location of the furance	Furnace cross section	d:D ratio	H/D/2 ratio	Stack angle	Furnace Volume (V_1) $V_1 = \frac{KD^2 H}{P}$ (m^3)	V_2= cm^3/kg of iron l (K=0.5)	Remark
1.	Madhya Pradesh	Circular	0.28	6.37	81.1	0.13	7916	Direct Reduction
2.	Rajdoha	Circular	0.28	5.77	80.1	0.14	7758	-
3.	Salem	Circular	0.51	3.97	75.9	0.22	-	-
4.	Mandla	Circular	0.21	2	64	0.23	-	-
5.	Chiglabecha (Koraput)	Circular	0.5	6.3	81	0.04	-	-
6.	Jiragora	Circular	0.3	4.6	77.8	0.02	6654	-,
7.	Kamarjoda (Bihar)	Circular	0.25	4.5	77.5	0.03	30150	-
8.	Bastar	Circular	0.83	6.6	81.4	0.23	-	-
9.	Madhya Pradesh	Rectangular	-	-		0.57	5285	Value of K should be Different
10.	Nagpur	Square	0.4	9.76	84.1	0.16	31987	-
11.	Nalanda Valley	Rectangular	0.28	9.76	84.1	0.24	48535	-
12.	Modern Indian Blast Furnace	Circular	0.7 to 7 0.77		81.9	760	358	Indirect reduction

D - Maximum diameter (Bosh)# d - Throat diameter# H - Furnace height# 0^o - Stack angle#

P - Production kg/heat# K - Constant (0.5) for soft ore# V_1 - Useful volume# V_2 - Volume cm^3/kg iron

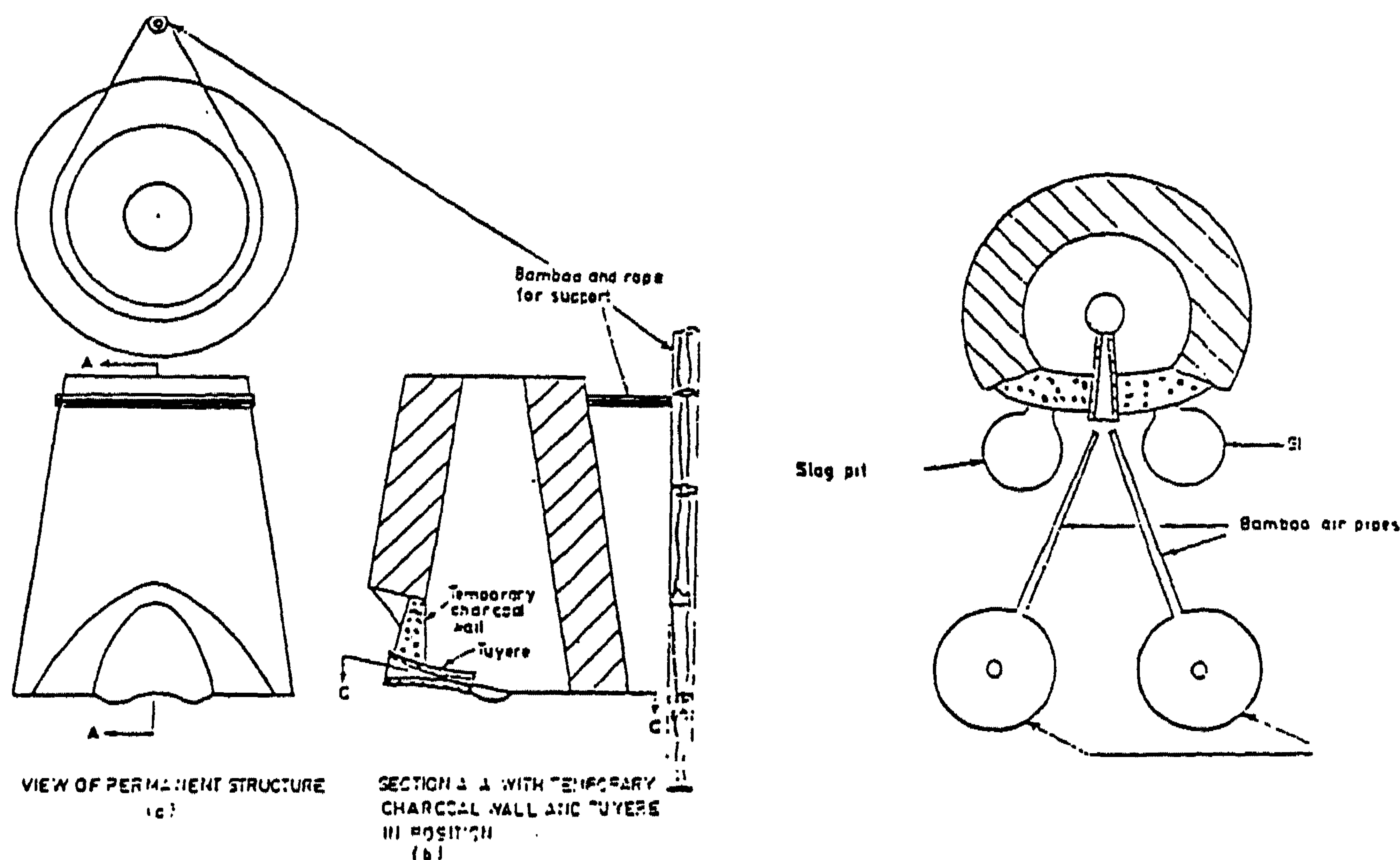


Fig. 29. Line diagram of the Iron smelting furnace reconstructed and operated at Bishunpur

through the bamboo and clay pipes. The bellow (*Bhāthi*) was either made from green bamboo sapling bent to form a circle of about 300 mm diameter or by taking a block of wood and giving it a shape like a trough having 300 mm inner diameter. In case of the bamboo ring two such rings were covered with the leather to give it a shape like a bellow and in the case of the wooden bellow only the top was covered with the leather. There was a hole in the top cover and a leather flap attached to it acting as one way air inlet valve. The bamboo pipe fitted to one side of this bellow was about 500 mm long and had a 12-15 mm diameter hole. The height of the side wall was about 80-100 mm. *Fig.30* shows a photograph of an old pair of bellows. The leather top of the bellow was kept taught with the help of a leather string tied between it and one edge of a green bamboo sapling fixed in the ground at an angle as shown in the figures. The pair of bellows was operated by a single man standing on them and pressing alternately. The operator used two sticks to support himself as shown in some of the figures. Sometimes in order to increase the force two persons stood on the same bellow. The only improvement made in the latter period to increase the size of the bellow and operate it by hand either by sitting by the side of it or with the help of a lever as shown in some of the figures latter in this text, used for melting of steel and non ferrous metals.

No further improvement was done in these bellows as indicated by the technology of China, Japan or Western countries because the ancient Indian smelters of iron had realised the fact that blowing excess air will lead to the production of brittle cast iron and not solid sponge or wrought iron.

(iv) *Preparation and operation of the furnace*: It was the duty of women to clean the surrounding of the furnace, roast the ore and break it into 3-5 mm sizes, store

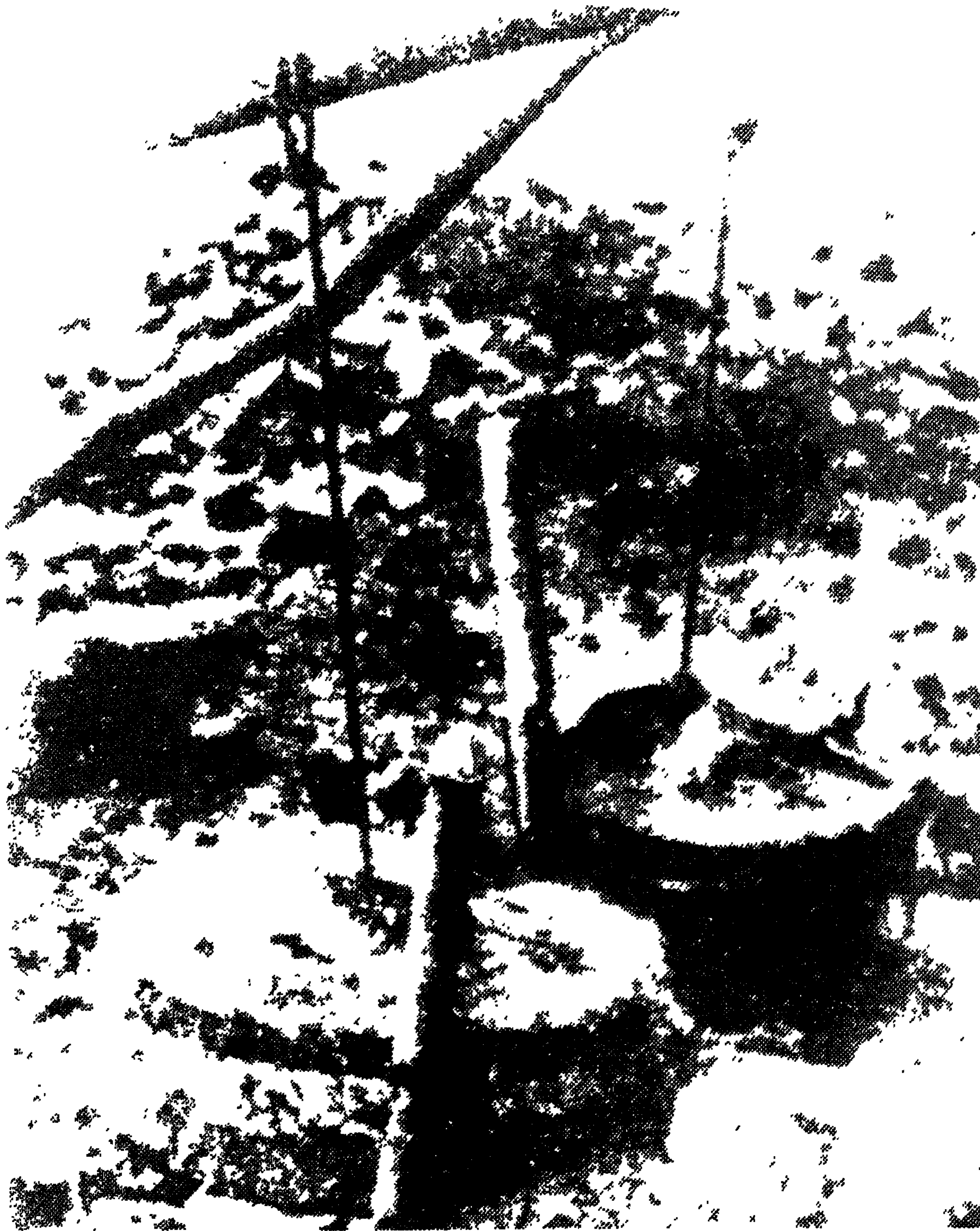


Fig. 30. Photograph of a pair of ancient Bellows made from hide.

sufficient quantity of charcoal and also repair the furnace with clay. They also prepared 'nari' clay, piled sand, earth and red iron ore dust near the furnace and also stored sufficient quantity of water in wooden *Kotana* (trough) and earthen pots.

The furnace bottom was prepared as explained earlier and after fixing the clay tuyere and bellows in position and closing the front hole the furnace was lit after performing the puja and charging it with charcoal. The furnace temperature was raised by operating the bellows at slow pace. When the furnace was red hot and CO gas was seen burning at the top. The furnace was charged with pre-heated ore and charcoal in alternate layers. The preheating of the ore was done by storing it on the inclined platform (*mācān*). *Table 5* gives the charging schedule and operating parameters of the Jiragora and Bishunpur and the latter furnace under operation. An oil lamp can be seen put near the furnace to take precaution against CO gas poisoning. The four thermocouples fitted in the furnace to record the inside temperature are also visible in this picture.

Table 5 — Comparison of operating parameters of Jiragora and Bishunpur iron making furnaces

	Operation	Time	Material charged Ore	Coal	Blowing Rate	Remark
Jiragora Furnace						
1.	Furnace Preheating	1 hr		8 kg	Faster than 87 strokes/min.	See Table VI
2.	Reduction stage	4 hrs		14 kg	87 strokes/ min.	Sequence of ore and coal charging not available.
3.	Consolidation stage	1 hr		8 kg	Vigorous blowing	
4.	Total operating time	6 hrs				
5.	Total material charged and metal produced	-	24 kg	30 kg		5.6 kg of iron
Bishunpur Furnace						
1.	Furnace Preheating	1.25 hrs	2.5 kg	3.25 kg	40-50 strokes/min.	Fce. Temp. 550 ° C
2.	Reduction stage	4 hrs.	8 kg	16 kg	60-70 strokes/min.	-950 ° C
3.	Consolidation stage	0.5 hrs.	1 kg	2 kg	110 strokes/min.	1500 ° C
4.	Total operating time	5.75 hrs.	-	-		2.5 kg of iron
5.	Total material charged and metal produced	-	11.25 kg	21.5 kg.		

During the operation of the furnace the bellows were worked at controlled pace to maintain the furnace temperature of 1000 to 1100°C.It took about 6 hours to complete one heat on small furnaces. During the last campaign of the heat the rate of air blowing was increased and a maximum temperature of 1500°C was achieved at the tuyere level. At this stage a small hole was made in the front wall to tap out the molten Fayalite slag. During this period the reduced sponge iron got consolidated in the hearth by partial fusion. The out flow of liquid iron-carbon alloy (C 2%) was considered to be a bad omen. After tapping out the final slag the tuyere and bellows were removed and the front wall was broken to take out the hot sponge iron block.

(v) *Handling of sponge*: The hot iron bloom taken out of the furnace was hammered on stone anvil to squeeze out the liquid slag as much as possible before it is solidified. This porous sponge iron block was repeatedly heated in a forge hearth to reforge and refine the wrought iron thus produced. The refining treatment can be called the secondary treatment.

(IV.2) Secondary Treatment of the Hot Sponge

After the hot sponge (weighing about 3-9 kg) was consolidated into a semi-porous mass by forging and squeezing out the molten slag ($Fe_2 SiO_4$) it was further refined to remove the remaining FeO and Fe_2SiO_4 slag and at the same time increase the density of the solid iron block or rod. For this the block was repeatedly heated in a forge hearth and SiO_2 was sprinkled on it so that remaining FeO may get converted into Fe_2SiO_4 or $FeO.Fe_2SiO_4$ Eutectic (M.P. 1170°C) i.e. fluid slag and flow out of the semisolid mass.

The iron piece was repeatedly forged to separate maximum possible quantity of the slag and convert the spongy mass into a solid rod of 15 mm dia x 150 mm length. This refined bar was classified into various categories on the basis of its ductility and appearance of the fracture. This standard refined wrought iron bar was sold to blacksmiths (Lohar) or steel makers for further refining and fabrication of various war weapons and agricultural implements etc. An assessment of the metallurgical properties of the iron produced by the Bishunpur craftsmen has already been published by Prasad K.K. et al. (1990)

(IV.3) Extraction of Iron from Biotite by Ayurvedic Method

In *Rasa Ratna Samuccaya* and other Ayurvedic text a number of processes have been mentioned for the extraction of iron from Biotite and other iron bearing minerals for the preparation of medicine. This process is known as *Satvapātana*, and generally consists of three major steps : (i) *Śodhana* (purification), (ii) *Bhāvana* (Maceration and Trituration),(iii) *Dhamana* (Heating and smelting).

Śodhana(RRS 2/16) is the process of purification involving heating and quenching of the mineral in some vegetable extract or liquid for several times (7 times or more). The liquids used for *sodhana* of biotite are :

(i) *Kānji* (Acidic fermentative liquid),

(ii) *Triphalā* quath (Decoction of a mixture of Terminienelia chebula, Termenelia belerica and Embelica officinalis).

(iii) Cow's urine.

(iv) Cow's milk.

This process is accompanied with intermediate *Bhāvana* and finally pelletization of the treated mineral mixed with certain other ingredients.The pellets are charged into a *Muṣa* (crucible) and heated to high temperature in *Aṅgār Koṣṭhi* shown in *Fig.31*. This sketch of the furnace, capable of attaining 1400°C,has been described in RRS text.

For the *satvapātan* of iron from Biotite (RRS2/28) the proportion of the charge materials is as given below.

Mica (purified)	-	200 gms
Borax (flux)	-	50 gms
Musali powder (reductant)	-	50 gms

To this powdered mixture sufficient quantity of water was mixed, pelletised to 25-30 mm balls and dried in the Sun. This process of extraction of iron from Biotite has been studied in detail by Jha et al. (1989) and they have concluded that maximum yield of the metal is obtained only by the charge mixed in the above mentioned proportion.

(IV.4) Classification of Iron-Carbon Alloy

The ancient knowledge regarding the classification of iron- carbon alloy was well developed and an idea of this knowledge can be had from slokas 70-71 of*Rasa*

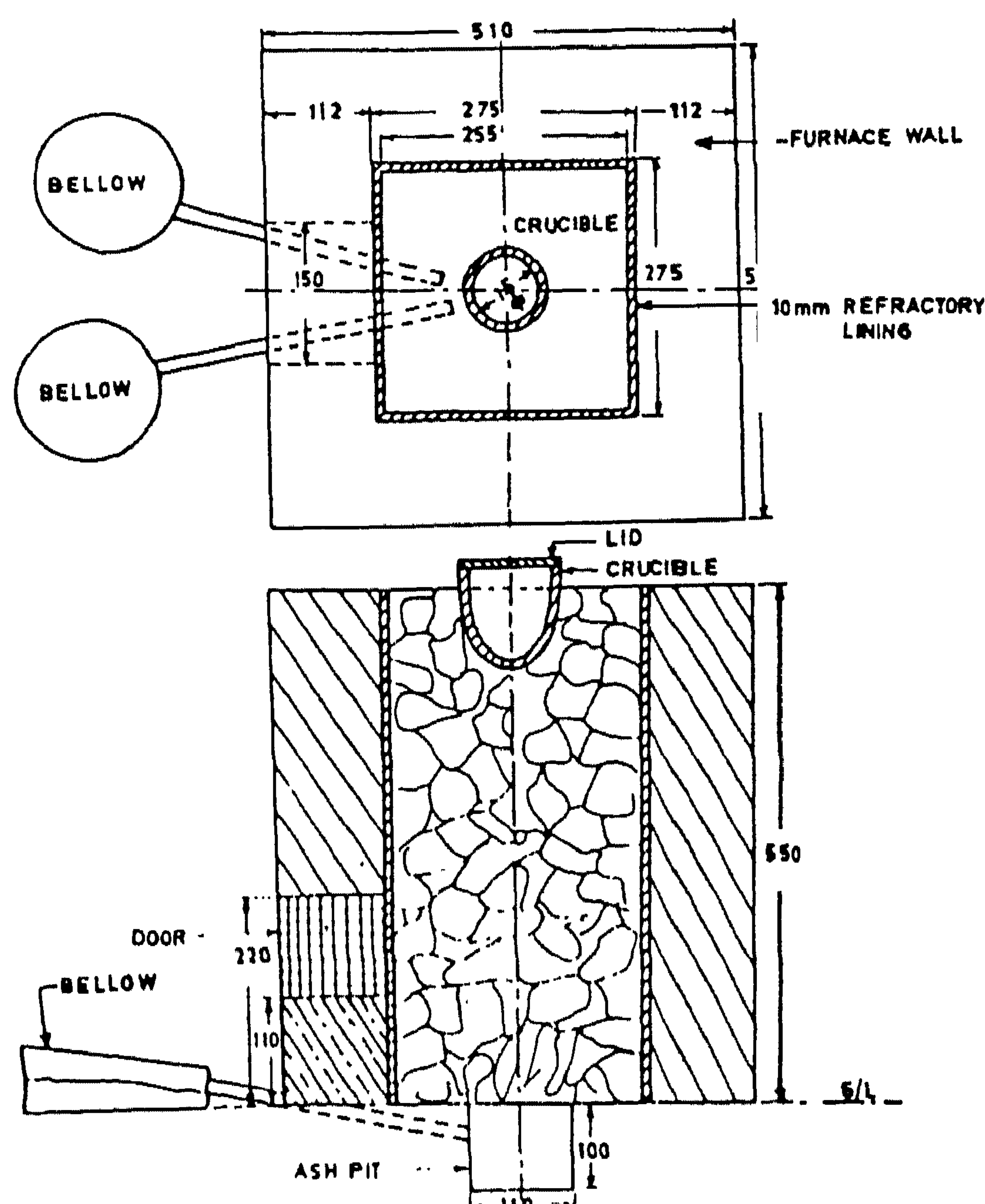


Fig. 31. Line diagram of 'Aṅgār Koṣṭhi' as described in RRS

Ratna Samuccaya in the 8th-12th century A.D. In this book the iron -carbon alloy has been classified into three main groups :

i) *Kāntā Loha* (soft iron)

ii) *Tikṣṇa Loha* (High carbon steel)

iii) *Muṇḍa Loha* (cast iron)

Based on the characteristic features of the fractured surfaces and other properties such as ductility, magnetism and hardness etc. these have been further classified into sub-groups as shown in *Fig.32*. This type of classification has no parallel in the world. Samuel(1980) writes that for the first time it was only in 1772 that 'Reamnur' distinguished between grey, white and mottled cast iron fractures. From the study of the classification of iron-carbon alloy, it is obvious that in India iron technology was much advanced and the ancient craftsmen were capable of selective use of various grades of this alloy. *Fig. 33* shows the solid state of the modern iron-carbon equilibrium phase diagram and the hatched band shows the range of iron-carbon alloys produced by the ancient Indians. It is very clear that these alloys were either soft iron (range X) containing little pearlite in the matrix of ferrite (low C steel 0.1 to 0.4% C), or (range Y) high carbon steel (0.7 to 1.5% C) containing cementite in a matrix of pearlite. In some steels the carbon content was found to be as high as 1.9%. It is also very clear that various categories of the iron-carbon alloy

Kinds of Iron (Loha)		Properties
Kānta Loha (Soft Iron)	Bhramaka	Very soft magnetic iron
	Chumbaka	Mildly magnetic, sticks to iron pieces
	Karsaka	It can attract iron objects
	Dravaka	Very strong magnetic iron
	Romaka	Permanent magnet, develops strong magnetic field arround it. It may be Ek mukh, or Sarva Mukh
Tikshna Loha (Carbon Steel)	Khara	Develops good cutting edge breaks on bending
	Sāra	Softer iron and it has fibrous fracture
	Hrnnala	Hard and tough has fibrous fracture
	Travaratta	Develops good cutting edge.
	Vajra	Has good hardening and tempering property has bluish colour and hard cutting edge
	Kala	Develops hard cutting edge after blue tempering
Munda Loha (Cast Iron)	Mrdu	Soft brittle iron may be grey cast iron. Has low melting point.
	Kunda	Mottled grey iron
	Kadara	White cast iron

Fig. 32. Classification of Iron-Carbon alloys as described in RRS (8-12 century A.D.)

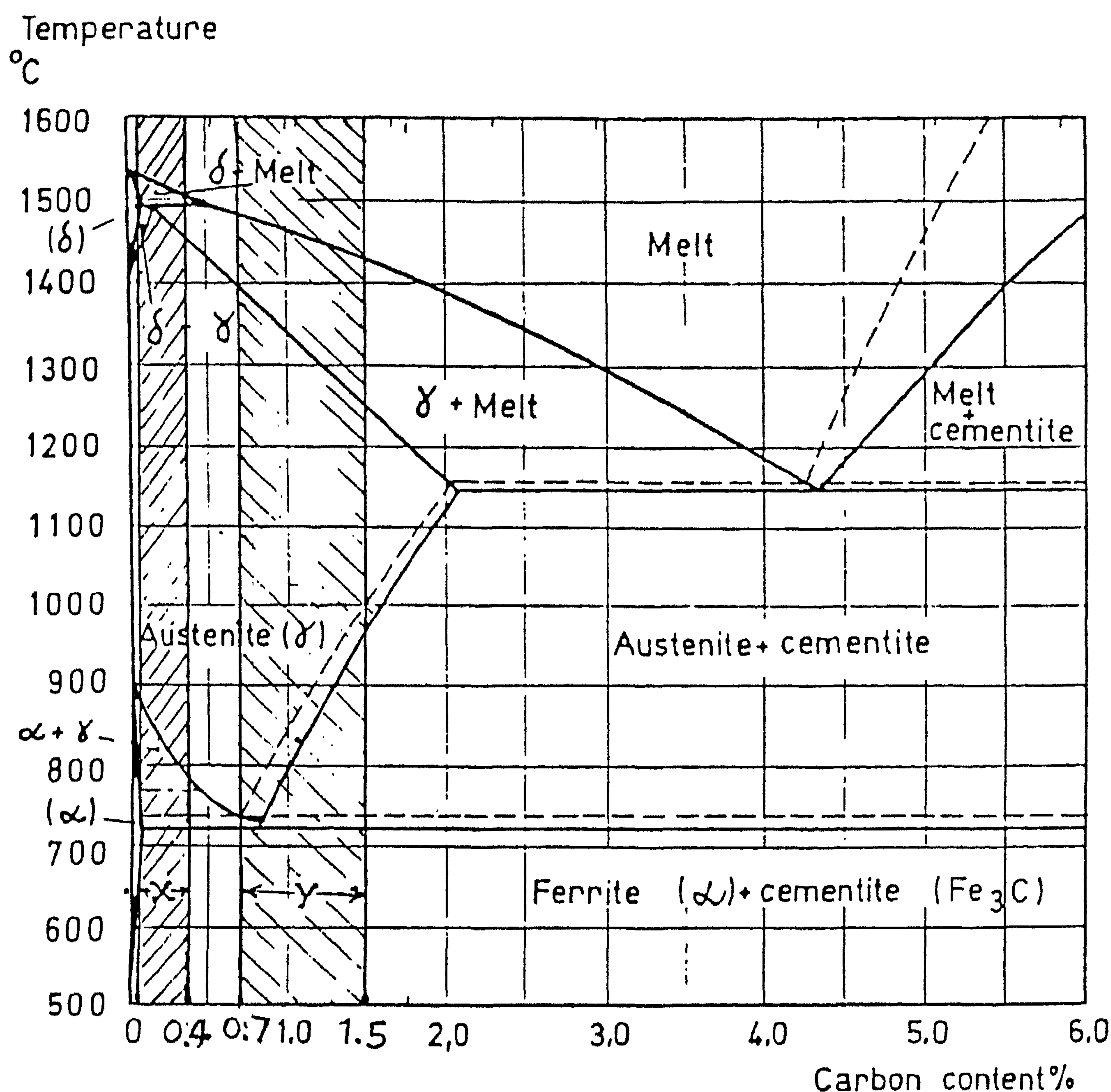


Fig. 33. Fe-C Equilibrium diagram showing the X and Y ranges of the Fe-C alloys produced in ancient times

were judiciously blended and used for different purposes as discussed later in this text.

(IV.5) Process Control During Iron Making

From the study of the phase diagram it is very obvious that the ancient Indian smelters had gained high level of skill in operating the iron smelting furnaces and they were applying strict process control to produce iron containing 0.1 to 0.4% C and rarely iron containing carbon in the higher range.

Prakash, B.(1990) has done a detailed study of the operating parameters and heat and mass balance of some of these furnaces and he has observed that the furnace temperature was controlled to 900 to 1000°C during reduction and raised to 1250 to 1300°C in the last phase by controlling the blowing rate of air as shown in *Table 5*. Bloomgren and Tholander (1986) have studied the constitution of iron smelting

slags and the environmental conditions inside the low shaft furnaces and they have concluded that Fayalite ($2FeO.SiO_2$) slag or its Eutectic with FeO having a melting point of 1205°C and 1170°C respectively prevent the carbon pick up by the reduced iron, and thus in this process the furnace productivity is decreased. *Tables 6 and 7* show the heat and mass balance for the Jiragora furnace operated by the tribals in the presence of Ghosh(1964) and this has confirmed the aforementioned

Table 6 — Heat balace of ironmaking furnace at Jiragora (M K Ghosh)

Sl.No	Heat Input	K Cal	S.No.	Heat output	K Cal
1.	Heat generated by combustion $CO/CO_2 = 4$	81,011.5	1	Heat for heating the ore to 1000°C	4,920.00
			2.	Heat for endothermic reduction	5,451.87
			3.	Heat content of metal at 1200°C	1,385.00
			4.	Heat content of slag at 1200°C	6,300.00
			5.	Heat in outgoing gases	48,026.28
			6.	Heat lost by conduction and radiation by difference	14,928.22
		Total 81, 011.5			81,011.5

% Radiation loss = 18.5%

Theoretical Flame Temperature = 1,938°C

Blowing Rate: Air blown in 6 hrs = 203 m^3

Air blowing rate = 564 litres/min

No of strokes for blower size

(280 mm dia, 100 mm ht) = 87/min

Note: Maximum capacity of worker = 300 strokes/min

Furnace operation practice :

	Operation	Time	Coal charged	Blowing Rate
1	Furnace Pre-heating	1 hr	8 kg	Faster than 87 strokes/min
2	Reduction stage	4 hrs	14 kg	87 strokes/min
3	Consolidation stage	1 hr	8 kg	Vigorous blowing

Table 7 — Material balance for ironmaking from Jiragora (M K Ghosh). Furnace trial results show 24 kg of ore/30 kg of charcoal. Time of reduction and smelting - 6 hours. Reduction efficiency 36.2%

Material	Analysis	Calculation	Metal Fe(kg)	Theoretical Composition	Actual Composition (basis 21 kg)	Gases (kg)	Remarks
Ore-24 kg							Metal Composition
$Fe(Fe_2O_3)$	63.4	24x0.634x0.302	5.5	9.7	9.66	2.357	C-0.4%
SiO_2	2.44	24x0.0244-0.021	0.01	0.565	5.68	1.387	Si-0.2%
P_2O_5	0.01	-	0.0004			0.114	Fe-rest
Al_2O_3	1.66	-	-	0.446	1.41	0.026	Slag
CaO+MgO	0.5	-	-	0.12	1.29	-	Composition
MnO	0.9	-	-	0.20	0.21	0.888	SiO_2-27.08%
LoI	3.7	-	-	-	-	-	Al_2O_3-6.72% Fe-46% MnO-1.026%
Total			5.5104	11.031			MgO-1.16% SO_2-0.075%
Oxygen in iron as FeO				2.77		*5.54 kg of	
Charcoal - 30 kg							iron will be associated with
F.C	75.8		0.022			22.718	21 kg slag.
Ash	3.2			0.96			Thoretical slag
V.M.	21.0					6.3	wt.=14.761 kg hence SiO_2+Al_2O_3
Total-54 kg				5.5324	14.761 theoretical slag wt	21 kg	
					54 kg*		Theoretical charcoal for reduction=16 kg

conclusions.*Table 8* gives the chemical analysis of some of the important iron objects and iron produced by the ancient furnaces.

(IV.6) Process of Carburization and Wootz Steel Production

As Kulkarni(1989) has quoted the Sanskrit text (*Ṛgveda* 9.112.2) and its Hindi translation by M.N. Banerjee(1929) the process of carbon alloying by carburization was known even in that period and the steel objects produced were sold at very high price. Hadfield(1912) has also mentioned the possibility of use of Indian iron chisels and even Indian craftsmen in building by Pyramids of Egypt.

The *Suśruta Saṃhitā* has mentioned the process of carburization by applying a carbonacious paste on the edge of the surgical knives and heating them to red hot condition, followed by hardening and tampering treatments to develop razor sharp edge (700 B.C.) which could split hair into two parts longitudinally.

The carburization of hot sponge or bloom could be done by the following techniques:

i) Increasing the carbon content of the hot sponge inside the smelting furnace by raising the furnace temperature and the retention time of the hot sponge for a slightly longer period.

ii) By increasing the temperature and the time of contact between the hot iron bar and charcoal during secondary refining.

iii) By selective carburization of cutting edge of the implements by the application of carburizing paste and reheating to 950 to 1000°C.

Table 8 — Chemical composition of iron produced by ancient Indian furnaces

	Insert	C%	Si%	Mn%	P%	S%	Others
1.	Delhi Iron Pillar	0.23	0.066	-	0.18	Traces	N2 = 0.0065%
2.	Bhubaneshwar Iron Beams	0.27 to 0.45	0.05 to 0.11	Traces to 0.04	0.015 to 0.018	0.006 to 0.015	Cr-0.9% Ni-1.6%
3.	Bastar Iron Axe (100 years old)	0.25 ot 0.45	-	-	-	-	Other elements in traces
4.	Jabalpur Iron (recent)	0.59	110 PPM	40 PPM	-	-	Cu-340M Ni-353 PPM Others in traces
5.	Bishunpur Iron (recent)	0.016 ot 0.043	-	0.057	0.02 to 0.2	0.007 to 0.013	-

Varahamihira (550 A.D.) (Ray, 1956) has mentioned the following processes for carburization and hardening of iron swords:

i) Make a paste of the gelatin from the sheep's horn and pigeon's, mouse's dung with the juice of the plant *Arka* (Caletropis gigantica) and apply this to the steel after rubbing it with seasam oil. Heat the sword in the fire and when it is red hot sprinkle on it water or milk of horse (camel or goat) or ghee (clarified butter) or blood or fat or bile. Then sharpen the edge on the lathe (Varāhamihira *Kharaglakṣṇam*, Chap.XVIX,Śloka 23-26).

ii) Plung the steel (high carbon), red hot into a solution of plantain ashes in whey, kept standing for twenty hours, then sharpen on the lathe.

The iron treated by the carburizing process suffered from the structural heterogeneity and non-consistency of quality as well as low fracture strength due to high inclusion rate. These difficulties were solved by the introduction of the process of production of Wootz steel.

(IV.7) Production of Wootz Steel

Ball (1881) writes that the 'Wootz' steel was much sought in the Eastern Mediterranean countries even earlier than Christian Era. The Indian masters had realised the effect of addition of 'C' to iron and the excellence of the cutting edges formed on such steel weapons. Wootz steel was being produced in several places in India and exported to the West even as early as 700 B.C. for the manufacture of famous 'Damascus Swords'. This sword had attained its reputation for edge sharpness, flexibility, strength and the typical surface structure on the sword's surface. *Fig.34* shows the typical surface structure of the sword developed by 'Damascusizing' and 'watering' treatments. Inspite of innumerable attempts made by the technician and metallurgists of the Western World this type of structure has remained a fascinating mystery. The details of these attempt have been reviewed in great detail by Piaskowski (1974), Yater (1983, 1983- 84, Thomsen (1987),

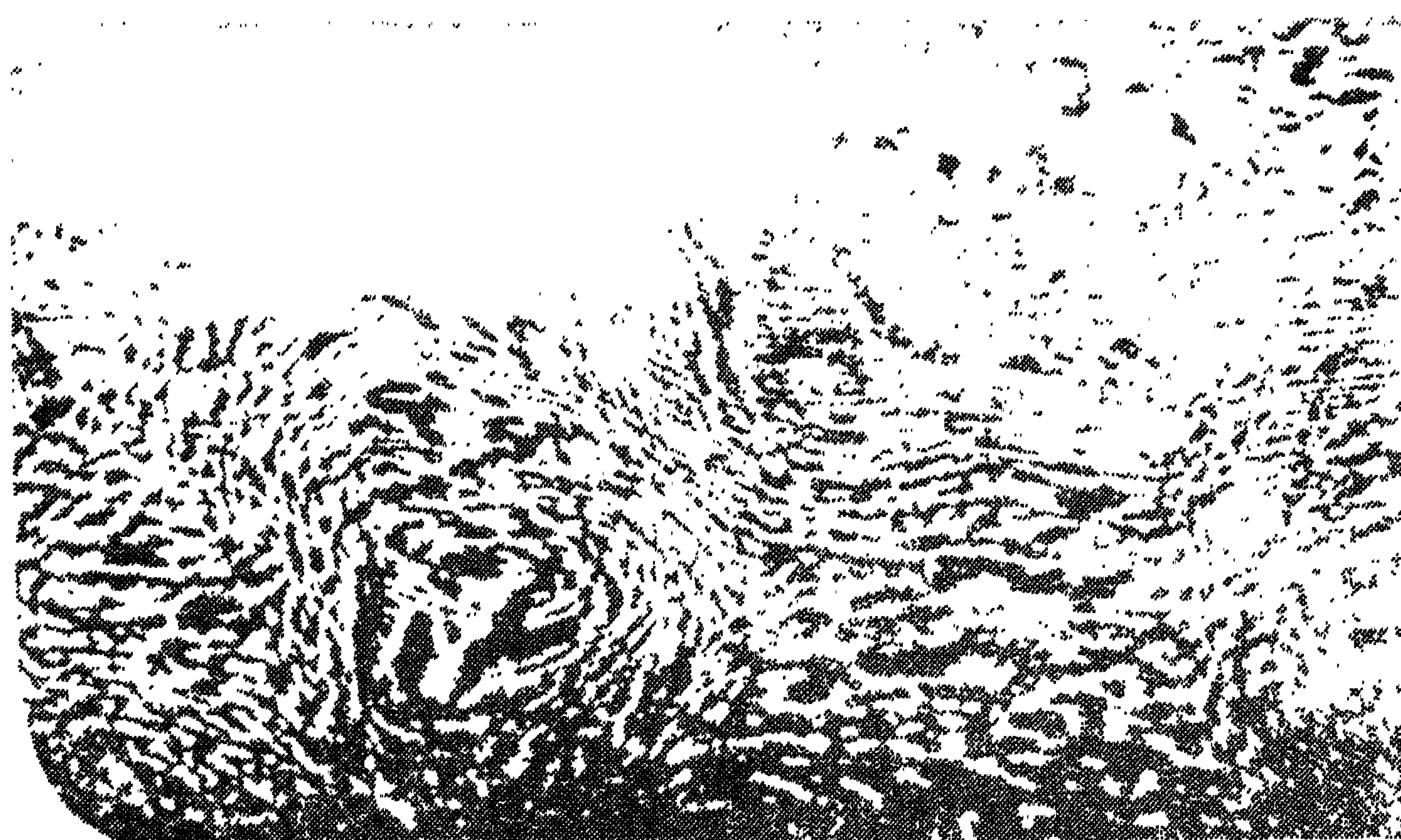


Fig. 34. Watering structure seen on 'Wootz' steel swords

Kedzierski and Stepineski(1987), Antiens (1987) and many others. Paiskowski has concluded that "Although the research on Dasamcene steel did not lead to its widespread production but the extent of interest shown by the research workers has enriched the imagination of scientists and has had a decisive influence on the development of science and technology". The latest study on the development of steel having this famous pattern has been by Verhoevens et al(1987). Raj and Sundaram (1990) have mentioned that in USA a patent has been obtained at Stanford for 'ultra high carbon steel' with 1.3% to 1.7% C (same as Wootz steel which has shown super plastic property along with hardness and strength and this may be produced in bulk for making the automobile and aircraft components.

Bronson (1986) in his review on this celebrated steel has questioned the origin of this Indian technology and tried to give credit to Iran or other Arabian countries who were in knowledge of the qualities of this steel and considered it worth while to journey to India to procure it, but after studying the classifi-

cation of Iron-Carbon alloys (commuñicated to him by the author) he has agreed to the origin and the production of molten steel in India. This technology was most probably developed for the first time either in Gujarat or Hyderabad. The English word 'Wootz' is supposed to be abbreviation of either Gujarati word 'Wuz', or 'Hooku' or 'Ukku' in Telugu language, which means steel or 'Pulat' in Persian. The other regions mentioned in the literature are Tamilnadu and Mysore where this quality of steel was made by the crucible melting technique. In the northern Indian crucibles and furnaces similar to those used in South India have been found, at Rajghat (Varanasi) and 'Khairadih' where most probably 'Wootz' steel was being produced between 600 B.C. to 1000 A.D.

The following two distinct processes have been reported by Yater (1983, 1983-84), Bronson (1986), Prakash,B. (1987) and Rao, K.N.P. (1989).

(i) By carburization of wrought iron rods and melting in small crucibles.

(ii) By decarburization of white cast iron.

In the first process steel was made by packing about 350 gms of small pieces of wrought iron into a clay crucible with 1/10th of its weight of chipped dry wood and leaves of specific plants e.g. Avaram (Casia auriculata) etc. and the crucibles mouth was sealed with clay. *Fig.35* shows the branch, leaves and flowers of Casia Auriculata. Sometimes a hole was made in the crucible cover for the escape of the gases produced inside the crucible. During heating 20 to 25 or some times more number of such crucibles were heated in a specially designed furnace where the central crucible could attain a temperature of more than 1550°C. The furnace as described by Buchnan(1807) and others gives an idea how the crucibles were shifted in a fixed order to the hottest zone of the furnace where the steel reached the molten state. After this crucible was either cooled slowly or it was water quenched. The process details and the time of one such operation have been summarized by Bronson (1986). The wrought iron charge could be carburized in about 2 to 6 hours and the extent of carburization was controlled by adjusting the proportion of wood chips in the charge and the residual amount of the FeO rich slag remaining in the wrought iron.

During the processing and melting of the steel molten slag was separated and clean steel ingot was obtained, which could be further classified and processed for the production of war weapons,tools and objects like wires for musical instruments etc. *Fig. 36* gives a macro-photograph of Wootz steel ingot published by Tylecote (1962) and *Table 9* gives some typical compositions of Wootz steel as quoted by Percy (1861) and Bronson (1986).

The crucibles used in this process had a conical or pear shape and they were very skillfully prepared from a refractory material capable of sustaining such treatment. *Fig. 37* shows a picture of conical crucible preserved in the National Museum of Madras,and also a sketch of the same is shown in *Fig 38*. These crucibles were prepared from a range of compositions based on their end use and these have been mentioned in the ancient Ayurvedic texts *Rasa Ratna Samuccaya* and *Suśruta Saṃhitā*. The crucibles used for making Wootz steel generally prepared from a mixture of some silicious clay or Caoline mixed with rice husk and iron oxide sand. On firing of these crucibles in reducing atmosphere at first at 400-500°C and then at 1100-1200°C, the rice husk got charred depositing carbon and adding SiO_2 to the clay. Recently Lowe et al. (1990) have analysed and studied the composition as well as structure of many such used crucibles collected from the steel melting sites of the Hyderabad region and confirmed the excellent refractoriness of these crucibles. The structure of these crucibles was found to be consisting of SiO_2 phase present in a matrix of Mullite (M.P. 1800°C), some graphite particles and small prills of iron, produced by the reduction FeO present in the crucible.

It is interesting to note that the use of graphitised refractory in the modern metals industry has been revived after about 200 years.

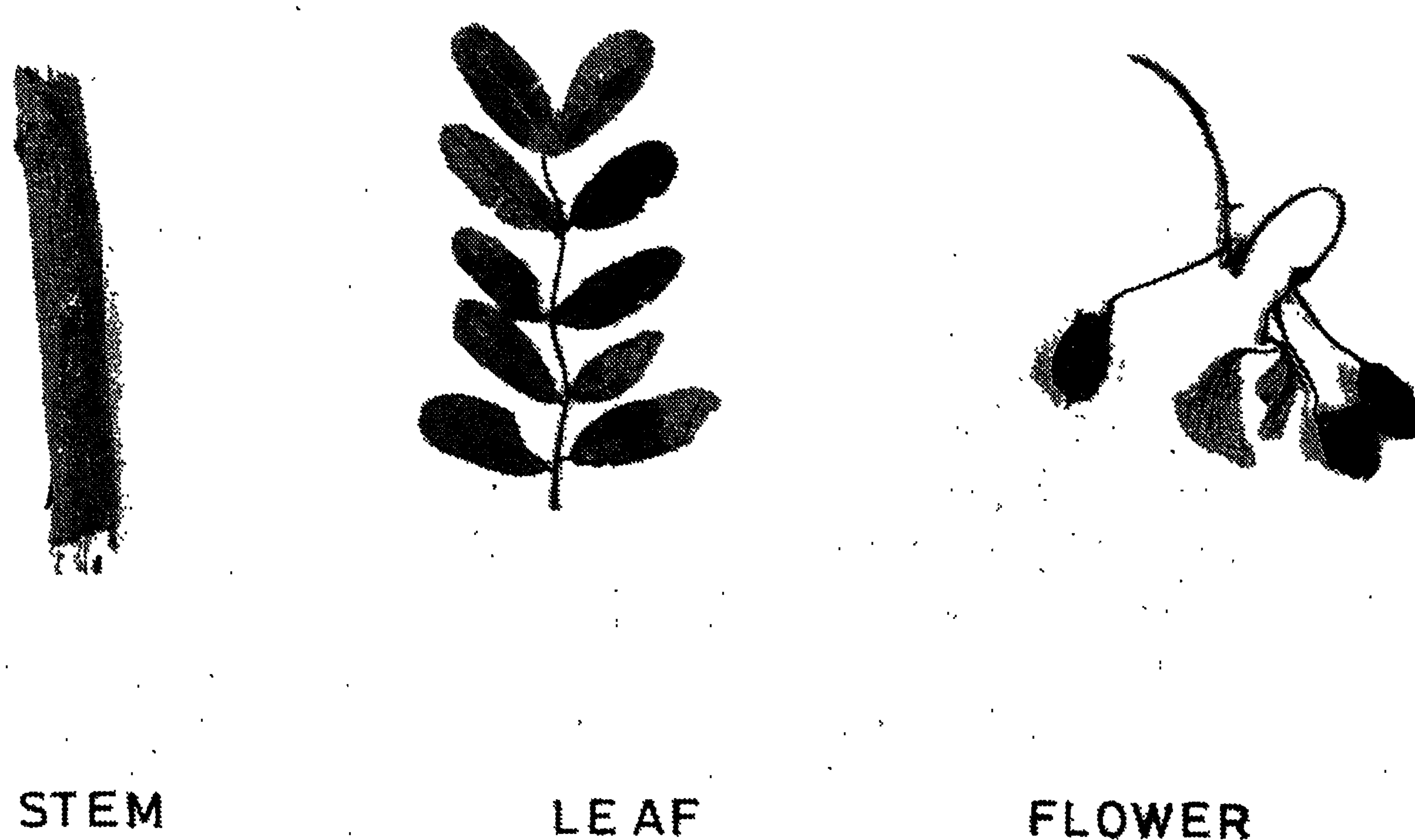


Fig. 35. Stem, leaf and flower of Cassia Auriculata (Avaram)

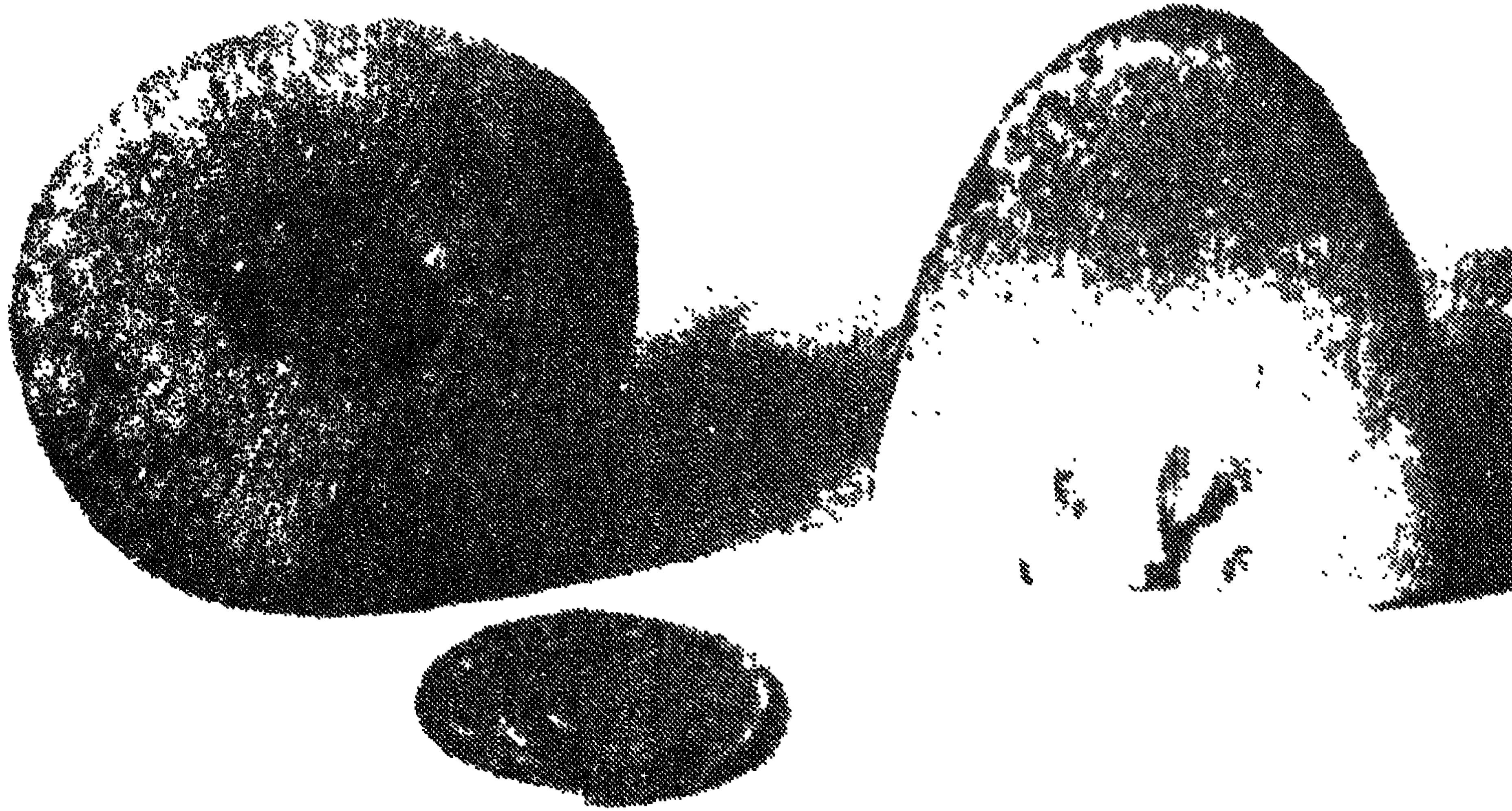


Fig. 36. Macrostructure of a Wootz Steel ingot

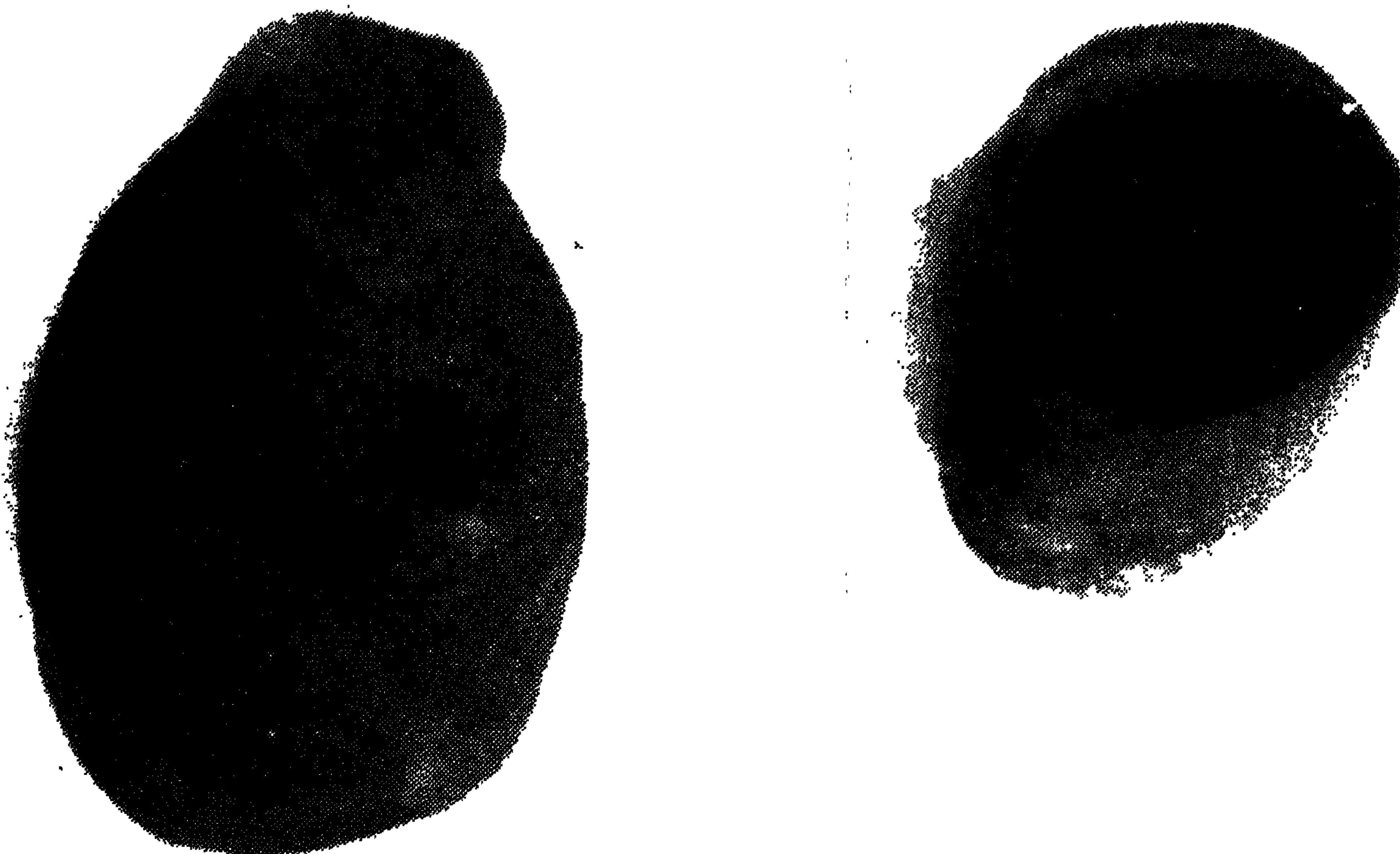


Fig. 37. Photograph of a Wootz Steel making crucible (from National Museum, Madras)

The second process of steel making was carried out in a pit furnace. In this furnace a molten pool of highly oxidizing molten slag was prepared from magnetite

Table 9 — Chemical Analysis of some 'Wootz Steel' objects

Sl.No.	Object	Percentage Chemical Analysis						
		Combined 'C'	Si	S	P	Mn	As	Others
1.	Wootz Steel Sri Lanka	1.97	0.07		0.07	0.02	0.07	-
2.	Indian	1.64-1.65	0.042 ot 0.045	0.17 0.18	-	-	0.037	-
3.	Mysore	0.963	0.127	0.02	0.007	-	-	-
4.	Damascus Sword	1.677	0.011	0.007	0.086	0.056	-	-
5.	Wootz Steel	1.33	0.045	0.180	-	-	0.045	Un-combined C-0.31

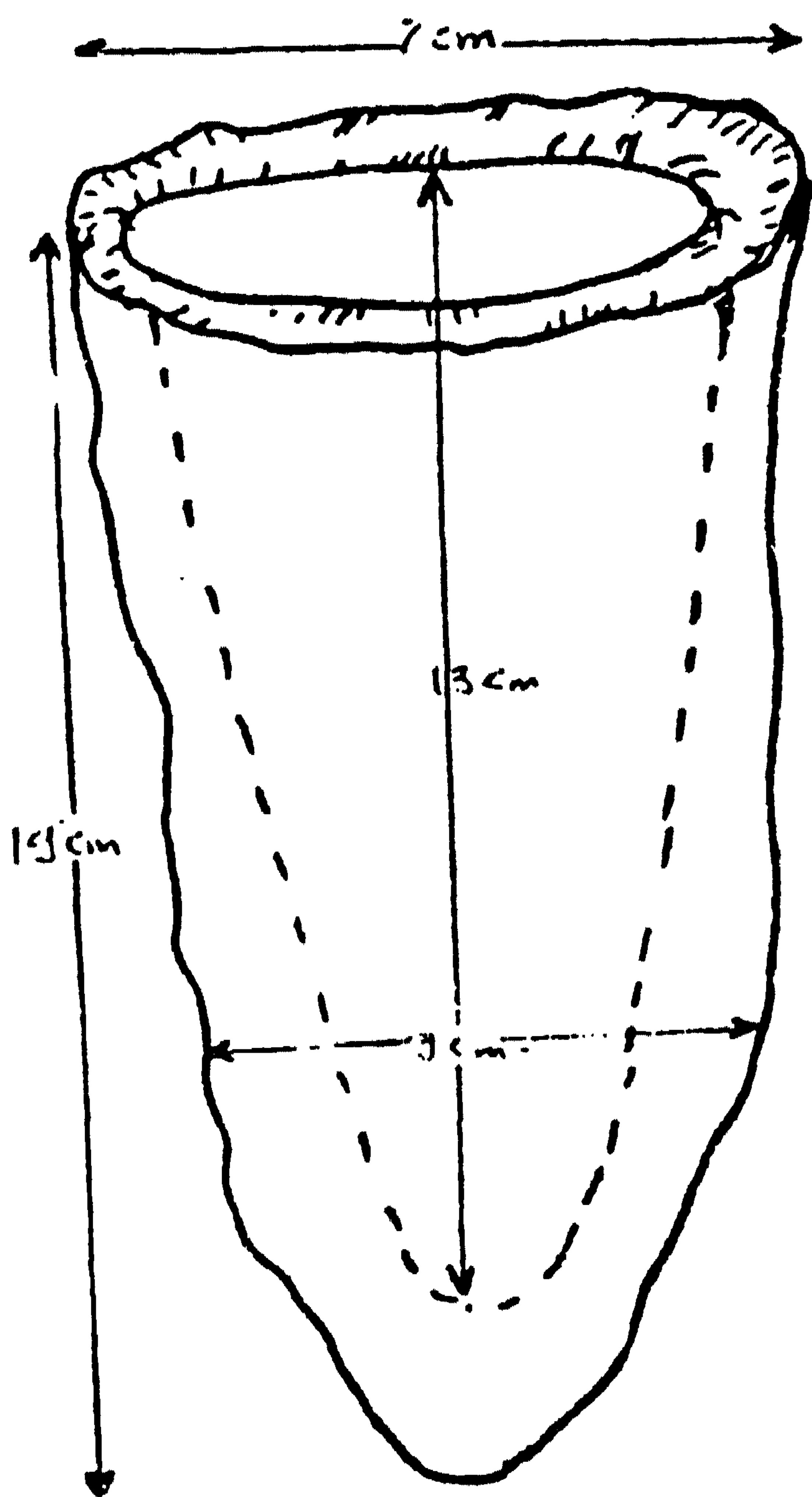
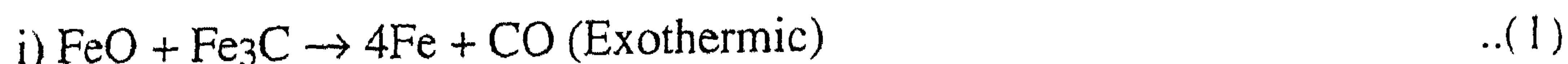
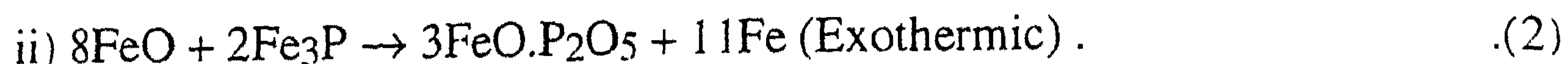


Fig. 38. Sketch of the same crucible

sand and quartz which had a melting point between 1170 to 1205°C and small red hot shots of white cast iron (produced by bloomery furnace) were dropped in this slag to get refined and produce steel. Two of the major reactions taking place were:



i) $FeO + Fe_3C \rightarrow 4Fe + CO$ (Exothermic) ..(1)



ii) $8FeO + 2Fe_3P \rightarrow 3FeO.P_2O_5 + 11Fe$ (Exothermic) . .(2)

Thus the white cast iron got decarburized and at the same time some dephosphorization also took place. Other impurities like Si and Mn also got easily oxidized by this slag. The heat of oxidation reactions as well as generated by the combustion of 'C' and CO gas produced sufficient heat to separate molten metal into a separate layer, which was allowed to solidify in the furnace itself and taken out as clean thick steel plate or disk and tested for its quality by making a 'V' shaped cut. Probably this was the steel disk or plate of 'Wootz' steel 'loaves' exported to the West as mentioned by Yater (1983, 1983-84) and Bronson(1986).

Yater (1983,1983-84) has postulated a third process where he assumes that the bloomery iron was first carburized in the solid state to pick up carbon upto 3.5%, which became molten in the crucible at 1300 to 1350°C, and then later on the solidified cake was decarburized by white heart malleablizing process.

In this process the high carbon white cast iron is packed in iron oxide powder and heated at 950°C for a very long period when the carbon is removed by diffusion and oxidation to CO. This postulation of Yater is most probably based on the combination of the above mentioned two processes and the process of malleabilization developed in the area of Birbhum (Bengal) mentioned by Mahamud (1988). Yater has proposed this process probably because of the prevalent belief that temperature of the order of 1550°C cannot be generated in a charcoal fired furnace, but authors calculation and the temperature measurement done by Prasad, K.K. (1990) et al. has proved it otherwise. The production of Wootz steel was in full swing upto the early 20th century and an estimate of its demand in Western countries can be had from the fact that in the 17th century according to Lowe, T. (private correspondence) one Dutch consignment of this steel consisted of 20,000 ingots shipped from our country.

(V) Zinc

Zinc is probably the last element to be discovered and used by the Pre-Christian civilization and the recent excavations done at the ancient lead and zinc mining site at Zawar (Rajasthan) by Hegde, Craddock and Sonawala (1984) has credited India to be the first to introduce this metal to the world somewhere between 600 to 200 B.C. Zinc is silvery white in colour and very hard and brittle owing to its close packed hexagonal crystal structure. It has a M.P. of 419°C and its boiling point is 930°C but it readily gets oxidized to ZnO at 550°C in open air. In the 17th and 18th century Germans called this metal 'Counterfeitum' or mock-silver because of its silvery white lusture. Owing to its brittleness this metal had not found much use in its pure form but it's alloy with copper became very popular due to its Gold like colour and excellent workability. From the debris and slag dumps found around Zawar, Hegde et al. have estimated that atleast 15,000 tonnes of zinc was produced

at this site over a long period and this metal was being supplied to all corners of the world ever since 11th century A.D. or even earlier.

The main minerals of zinc in nature are Calamine ($ZnCO_3$) and Sphalerite (ZnS), and mostly these occur in combination with the minerals of copper, lead, silver and iron. The mixed Zn, Pb, Ag and Fe sulphide deposit of Zawar in the Aravali hills near Udaipur has been known to be extensively worked in 11th century A.D., and zinc metal was being extracted by a novel technique of down draft reduction-distillation process which has led to the development of the modern industrial process adopted all over the World.

(V.1) Mining of Zinc Ore at Zawar

Paliwal, the mining superintendent of Zawar mines about three decades back, had noticed the signs of ancient mining of the Zawarmala deposit while planning the modern exploitation and he had tried to preserve a part of the ancient working. He had also noticed the abundance of the clay retorts thrown away near the mine's site. It is in 1981 that the importance of this ancient industrial site has drawn the attention of an Indo-British group, who took interest and located the remains of the ancient zinc extraction furnaces as well as studied the ancient mining method in detail (Freestone, Craddock, Hughes and Paliwal, 1985). Willie (1989) has described in great detail the ancient mining technology at this mine. He has concluded that the host rock at Zawar is metamorphised sheathed hard and compact dolomite, except within the weathered zone. The abundance of charcoal waste and ash found on the floor of the old mine has indicated towards the mining by fire setting method, which must have created acute ventilation problem inside the mine.

Signs of ancient working have been found at depths of well over 110 m and by cutting tunnels at depths of 470 m in the Zawarmala hills. The mine has been worked by a form of pillar and stall technique, with both being very characteristically rounded by fire setting. *Fig.39* shows the inside view of the mine with an old scaffold. Some of the deeper parts of the mine were certainly below the water table and these were worked by 'finger stoping' with declined galleries 3-5 m diameter radiating down the depth of upto 50 m from the wider stopes or chambers above. The inner side of the mine was worked very methodically, the floor was kept clean and well lit by oil lamps placed at suitable distances. Clean drinking water was also put in large earthen jars. Transport of the ore, waste, timber and water must have been a major task and for this good pathways were made with wood and stone. Wooden scaffolds were used for piller's removal, preparation of water dams and launders for the transport of material from one level above to the main ground level. *Fig. 40* shows some of the iron tools, hammers and chisels found inside the mine.

(V.2) Mineral Processing

On the outer slopes of the hills ample evidence has been found about the techniques used for breaking and beneficiating the ore. The ore mineral was hand picked and broken, when necessary, using stone hammers and slightly hollowed work stones as shown in *Fig.41*. A series of cup like hollows in conveniently placed hard rock out-crops have also been found which might have been used either for ...ding the ore or for gravity separation of sphalerite from Galena with the help



Fig. 39. Inside view of an Ancient Zinc ore mine at Zawar. Inside view of the same mine showing wooden scaffold and support



Iron hammers and chisels from Mochia mine.

Fig. 40. Some mining tools of iron found inside the Mochia mine, Zawar

of water flowing down the slope. The product was pea to sand size mineral and waste, found scattered over a wide area adjacent to the load.

(V.3) Smelting of Zinc Sulphide Ore

Zinc is one of the few metals produced by the reduction distillation technique even today because the commercially viable reduction of ZnO by 'C' is obtained only above 1200-1300°C while the boiling point of zinc is 930°C only. Hence, the metallic vapour produced after reduction has to be cooled at a fast rate below 500°C to produce liquid metal and prevent its reoxidation to ZnO (blue dust). Craddock (1885) has recently published a comprehensive review on the distillation technology and the apparatus used in ancient times in various countries, and he has concluded that in India the process of distillation of water, wine (*Somarasa*) and

probably mercury were known even in the Vedic period (*Yajurveda*). The distillation apparatus found near the ancient Taxila (Needham) was unique and much advanced. This system uses a separate condenser tube fitted to the mouth of the distill to carry the vapours to the condenser vessel which was water cooled.

Ray (1956) has reported the use of similar apparatus (*Damru Yantra*) used for the preparation of Ayurvedic medicines.

The process used for the distillation of zinc by the Indians around Zawar mines is unique in the sense that it is designed on the principles of down draft distillation. *Fig. 42* shows a picture of this distillation apparatus as described in *Rasa Ratna Samuccaya*. In this '*Yantra*' the solid charge was held in the upper inverted pot by sealing its mouth with clay and fixing a reed stick in the centre for the escape of gases etc. at high temperature. Another matching earthen pot was luted to the mouth of the inverted pot as shown in figure and the bottom pot was kept into a trough full of water. During the processing the upper inverted pot was heated by building a fire on a platform around it. On reaching the cherry red temperature (600°C) the reed was charred and burnt off and the reduced metal vapour Zn or Hg was forced downwards in the condenser where it got converted into liquid or solid metal. A similar but advanced method was used by the Zawar smelters. The process used by them consisted of the following steps:

(1) Sizing and Roasting of Sulphide Ore: After sizing and beneficiation, as described earlier, the ore was mixed with charcoal dust and fired into a heap to convert it into oxide by controlled roasting in an oxidizing atmosphere. During this process ZnS, PbS and other sulphide mineral got converted to their respective oxide but no reduction of these oxides by carbon was permitted.



Fig. 41. Stone Pestal and Hammer used by ancient Zn smelters at Zawar

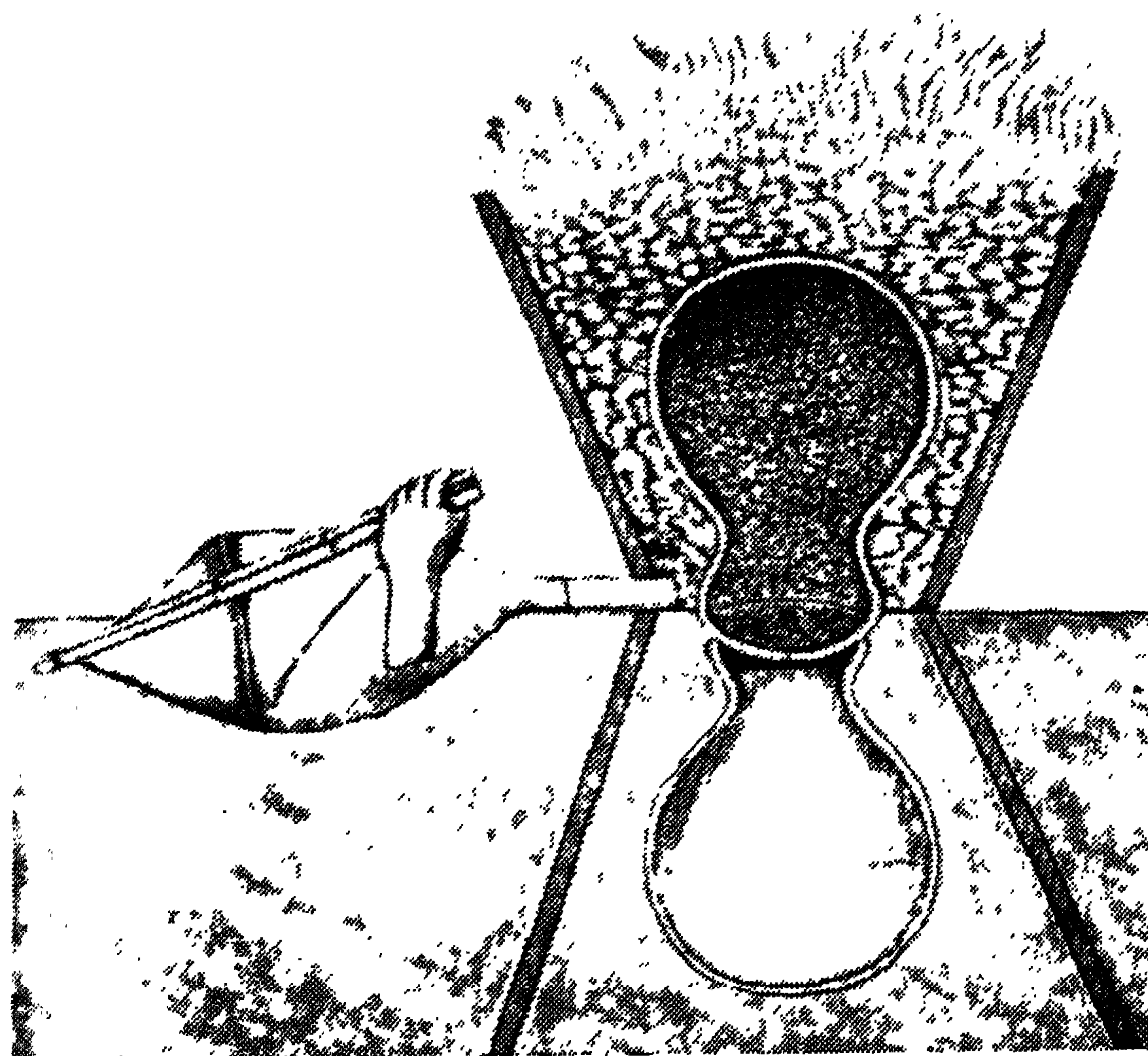


Fig. 42. Artists impression of down draft distillation apparatus used for production of Hg, Zn, etc.

During this process Pyrite helped in the transfer of sulphur from Zn and Pb etc. to Fe to form FeS or finally get converted into FeO releasing SO_2 gas.

(ii) Mixing of the Charge and balling: The roasted ore was mixed with more charcoal powder, salt and borax as flux and thoroughly mixed with cow dung and water, and then made into balls of 5 to 10 mm dia. by hand rolling. These pellets were dried in Sun and then filled into the brinjal shaped retorts.

A large number of these retorts has been found at Zawar. They are of two principal sizes with capacity of 750 c.c. and 2000 c.c., *Fig. 43* shows a photograph of two of these retorts. As described in *Rasa Ratna Samuccaya*, the main retort or crucible in the shape of a brinjal was made from a clay mixture consisting of locally available refractory clay, rice husk and sometimes mixed with iron ore dust. A large number of such compositions have been mentioned in the ancient Indian Literature.

After the crucible was dried up it was filled with the charge pellet and its mouth was sealed after inserting a piece of reed stick and attaching over the stick a clay pipe shaped like a tubular end of the Dhatura flower, which was 8 to 10 digits long. The condenser pot was fabricated separately and fitted to the tube after the retort has been placed on the perforated bottom plate of the furnace. *Table 10* gives the chemical analysis of the retort clay. Lowe et al. (1990) have done detailed study of similar material used for the manufacture of 'Wootz' steel crucible and they have found it to be consisting of 'mullite' network with free quartz, graphite and some prils of iron.

Till 1981 the exact details of the retort furnace was not known, but during the recent excavations Hegde et al. (1984) have unearthed a set of three furnaces intact



Fig. 43. Photograph shows two of the zinc retorts found at Zawar

with the bottom plate *Fig.44* shows a sketch of the furnace assembly prepared by the excavators on the basis of the study of the furnace. As seen from the hearth of the furnace it consisted of four perforated bricks (55 mm thick) each containing 9 large holes (35 mm dia) to accommodate the condenser neck and 26 smaller holes plus 9 holes shared with neighbouring bricks for the passage of air into the furnace and for ash to drop through. These bricks were supported on a central peg and the side walls of the furnace. The square furnace was 660 mm by 69 mm at the base and curved at the top as shown in the sketch. A battery of such furnaces was constructed in a row and operated. The construction and operation of these furnaces has been described in detail by Hegde (1986) and Craddock et al. (1985) in a number of papers. The examination of the furnace remains by the British Museum Research Laboratory has established that the upper chamber of the furnace (*Kosthi*) was raised to the temperature of 1200 to 1300°C and maintained for 4 to 5 hours by burning wood or mixture of cow dung cakes and wood etc.

(V.4) Physicochemical Changes Occurring Inside the Retort

As the temperature of the furnace was raised the refractory of the retort got sintered and graphitised and at the same time the following chemical reactions took place inside the retort. At temperature below 1000°C PbO and Ag_2O present in the ore got reduced by carbon producing liquid Pb-Ag alloy and CO gas. At the same time the reed plug got charred and burnt releasing CO gas inside the condenser chamber where it expelled out the air from this chamber and created a reducing atmosphere. At the same time the liquid alloy of Pb-Ag trickled down through the hole and got collected inside the condenser vessel. This must have been followed by the reduction of ZnO to Zn vapour and CO gas at 1200- 1300°C, which were

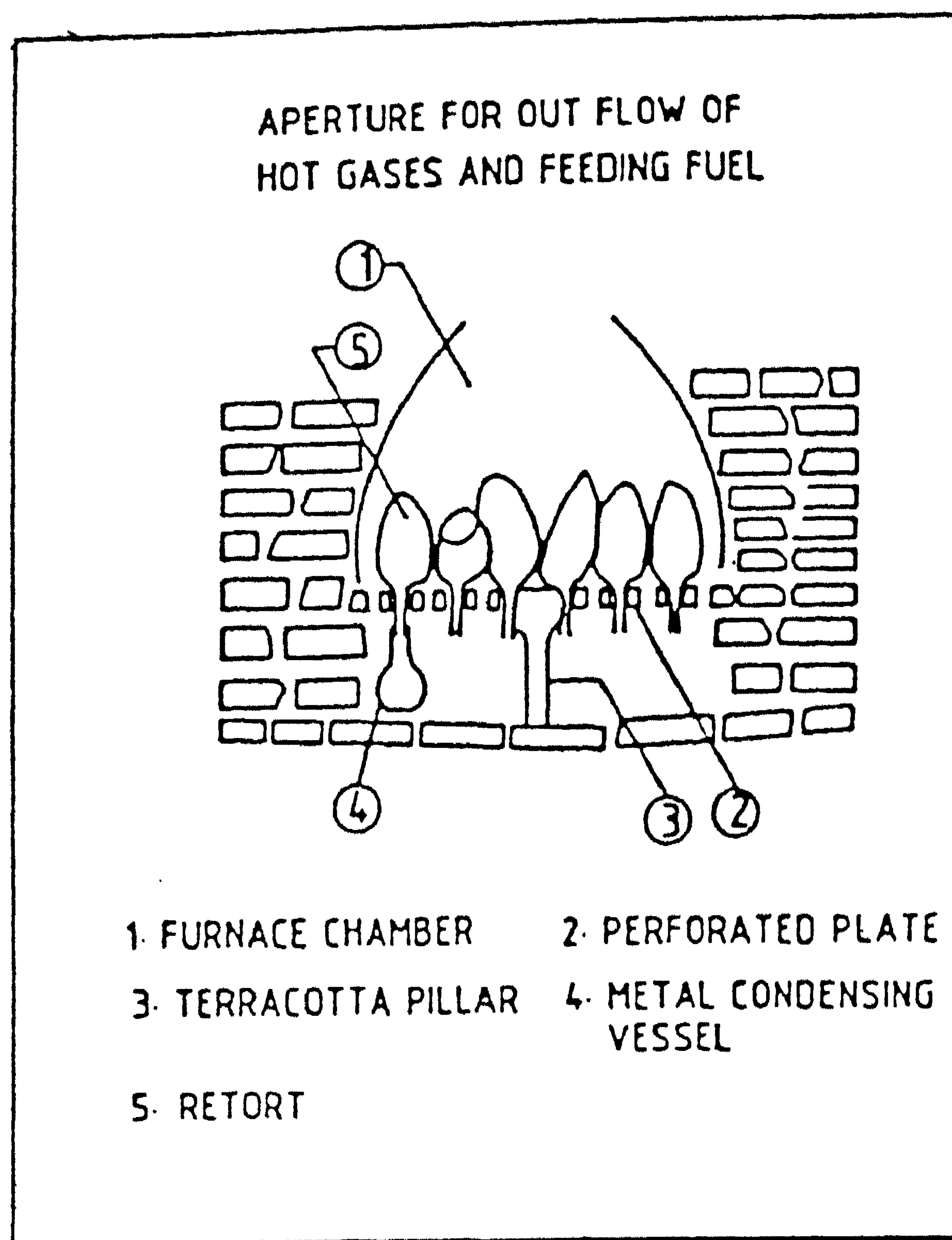


Fig. 44. Sketch of the complete zinc retort furnace, showing retorts and condenser vessel in position

forced through the small hole in the retort. As this mixture of Zn vapour and CO was forced through the condenser tube liquid Zn metal must have been produced below 580 °C by the following triple action.

(a) Cooling of the gas to the jet action of the vapour i.e. sudden volume expansion leading to lowering of vapour temperature.

(b) Chilling action of the Pb-Ag alloy already collected in the condenser at low temperature.

(c) The cooling action of the air draft in the bottom chamber.

At the same time Borax and salt added to the mixtures must have helped in low temperature sintering of the charge as well as slag formation. The studies carried out by Gangopadhyaya et al. (1984) on the retorts and debris of the Zawar area have shown that the material remaining after the distillation was both as fused slag as well as sintered mass and their analysis was as given in *Table 11* with respect to Zn, Pb, Fe and S. This table also gives the metallic content of the retort wall, and from the study of this table it is very obvious that major part of the Zn was extracted leaving only 3% Zn in the residue, and the density of the retort wall was good

Table 10 — Mineralogical Analysis of the Ceramic Material of the Zinc Retort Wall.

	(1)	(2)	(3)	(4)
SiO_2	62.49	53.82	57.96	64.85
TiO_2	0.71	0.27	0.44	0.59
Al_2O_3	13.90	17.49	13.75	13.97
FeO	2.48	4.16	7.49	15.39
MnO	0.04	b.d	b.d.	b.d.
MgO	1.44	1.29	0.93	1.35
CaO	0.64	0.34	0.39	0.70
Na_2O	0.94	1.81	0.67	0.55
K_2O	3.08	3.11	9.90	7.54
P_2O_5	N.A.	0.50	0.28	b.d.
Cl	N.A.	0.16	b.d.	b.d.
S	N.A.	b.d.	b.d.	b.d.
ZnO	2.18	3.22	0.61	0.61
Total	87.90	86.17	99.11	98.66

Note :- (1) Bulk analysis 'crushed slice' AAS

(2) Clay Analysis EPMA

(3) Partial melt (glass on surface) EPMA

(4) Same as (3)

Table 11 — Metallic Content of Zawar Charge Residue and Retort Wall.

		% Ag	% ZnO	% Pbo	% Fe	Reference
1.	Coarse fraction of carrier (residue)	0.023 to 0.012	0.61 to 0.3	0.36 to 0.04	—	Freestone et al. 1985
2.	Fine fraction carrier (residue)	0.01	0.122	0.26	—	"
3.	Charge residue loose	—	3.04% Zn	Traces	7.60	Gangopadhaya et al. 1984
4.	Slag inside the report	—	2.74% Zn	Traces	9.52	"
5.	(a) Retort Body	—	2.19	0.3	—	Freestone et al, 1985
	(b) Retort Body	—	Traces	Traces	4.37	Gangopadhaya et al, 1984

enough to prevent the diffusion or escape of Zn vapour through it. The lower Pb and Ag content of the residue shows that either the mineral of these metals were completely separated by beneficiation prior to the preparation of the charge pellet or these metals got Co-extracted as described above.

In the author's opinion the Co-production of Pb-Ag alloy and Zn-Ag alloy is more probable because Pb and Zn have very restricted solubility and silver can alloy with both these metals. Hence, these alloys will be solidified in the condenser in two separate layers which could be easily separated. Afterwards Pb-Ag alloy could be refined by cupellation technique to produce Ag and PbO, and PbO may be treated in a separate furnace to produce lead. The surrounding area of Zawar has been also known for the production of these metals ever since pre- Harappan period. The process has been so successful that in 18th century Champion designed his vertical report on similar principles as described by Craddock(1987). It is also surmised that this as well as the Belgian report furnace (19th century A.D.) were designed after studying the Indian distillation system.

(VI) Production of some other Metals

Tin, Mercury, Arsenic and Antimony have been known to the ancient Indians and they have been used either as alloying element or for some other purposes, but their existence and use as virgin metal is doubtful. These metals have played their role in the development of metals technology in their own way, such as the alloying of tin with copper has introduced the bronze age and mercury has been a prime media in the alchemical processes as well as preparation of Ayurvedic medicines. A short description of the knowledge of these metals is given below:

(VI.1) Tin

Mention of Tin(*Trapu,Vanga*) has been made in Vedas (*Yajurveda* 30.14) but no extraction process or specific use has been described till the introduction of bronze. In India very meagre deposits of tin bearing ore have been reported from Hazaribagh and Chota Nagpur area and most probably this metal or its oxide mineral Cassiterite was brought from Burma or Malaya. One of its name *Vanga* is probably derived from the Eastern part of Bengal where probably its use was begun. Murthy and Rao (1990) have recently published a detailed review of tin in Ancient India. The earlier bronze was most probably made by co-reduction of mixed ore of Casseterite and Cuprite or oxidized Chalcopyrite. In the Bastar district of Madhya Pradesh the local tribal craftsmen are still continuing the traditional method of production of bronze metal and bronze idols and other objects using the ancient 'cire- perdue' technology. Tin has also been used to prepare low melting soldering alloys and coinage metals. These will be discussed in more detail under preparation of alloys.

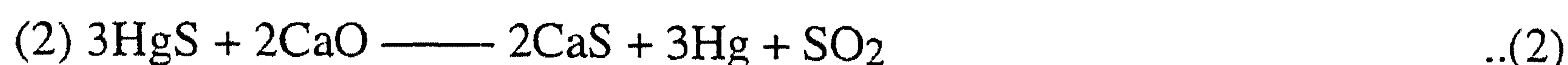
(VI.2) Mercury

The age of introduction of Mercury to the ancient Indians is not demarcated very clearly but it is sure that this metal or its minerals have not been mentioned in the Vedic text.It is also not very clear whether *sindur* used by married Indian women was HgS mineral although this compound has been called *Rasa sindur* in the

Ayurvedic text *Caraka Saṃhitā*. In Sanskrit this metal is called 'Parada' or Rasa and Hg as well as HgS have been extensively used in the preparation of Ayurvedic medicines. In *Rasaratna Samuccaya* and other literature on '*Rasasastra*' description of use of Cinnebar (*Hiṅgula*) to produce Mercury (*Hiṅgulakrasta Rasa*) has been described along with the details of the distillation apparatus used for its extraction. HgS gets decomposed very easily on heating in air or with lime to red hot temperature. The reactions are as follows:



(1) $HgS + O_2$ —— $Hg + SO_2$ ..(1)



(2) $3HgS + 2CaO$ —— $2CaS + 3Hg + SO_2$ ..(2)

The Ayurvedic literature also describes the process of purification of this metal and its reconversion to HgS for Mercurial preparations. In latter period Hg has found its use also in amalgamation process for the extraction and over laying or coating of Gold and Silver (Gilding) on copper or brass objects as well as for the extraction of Gold from very lean ores. In the Medieval period with the progress of the alchemical processes its use has increased in many other areas such as thermometry etc.

(VI.3) Arsenic

It is found in nature mostly as Arsenide (As_2S) and as As_2O_3 which have a very low boiling point. Although the hardening effect of this element on copper was known from antiquity this element in the metallic form was known only in 1694. Earlier Arsenic sulphate found in the copper sulphate ore was probably co-reduced to produce Cu-As alloy which had higher hardness (220 to 230 BHN) as compared to the cold worked copper. This property was well recognised by the copper age people and used to produce hard and sharp edge on copper weapons.

(VI.4) Antimony

Antimony sulphate (Stibnite) has been known to the ancient people (4000 B.C.) as black colouring agent, or toiletary for colouring eye brows. It was also being used for the preparation of '*Surma*' an Ayurvedic medicine used for the cure of eye diseases and also as toilet material. Sb_2S_3 readily gets oxidized to Sb_2O_3 at 290 to 500°C and on fast heating it volatilises at 650°C. It can be easily reduced by 'C' to produce Sb metal which is also known as 'Star Metal' owing to its structure. No mention of this metal has been made in ancient Indian literature nor artifact bearing this metal in recognizable quantity has been obtained during archaeological excavations. In the latter period this metal has been alloyed with lead etc. to develop bearing and typing alloys.

The discovery of other metals and elements of the periodic table had to wait till the age of alchemic and experimental chemistry in the West. In fact during the 17th to 20th century while the concept of modern chemistry and metals technology were being developed and industrialised, in India the ancient art of metals technology was being lost owing to the religious rituals and concept of secrecy associated with the Indian practices, and it also suffered serious set back due to the political disturbances.

Alloy Technology

The chemical analysis of ancient metal artifacts have revealed the presence of many other elements in minute quantities affecting the properties of the parent metal many a times favourably. For example the copper artifacts containing 2-5% Arsenic have been reported to have better hardness than pure copper but it is difficult to say whether this alloy originated from the arsenic bearing complex sulphide ore or Arsenic metal deliberately added to copper to produce this alloy. In exceptional cases copper containing 20-24% Arsenic have been reported and this must have been definitely made by alloying. Most probably the acquaintance with first alloy might have been accidental due to the coexistence and co-reduction of two or more metals but after observing the beneficial effect on strength, hardness, hot and cold workability, lusture and corrosion resistance ancient craftsmen must have started adding these metal deliberately and thus the alloy technology must have been born. The acquaintance with the naturally occurring Au-Ag alloy 'Electrum' found at Kolar might have been the first introduction of Indians to the difference between the property of pure Gold and Au-Ag alloy. The history of production technology of alloys most probably begins with the manufacture of bronze or Fe-C alloys of known composition, but it is difficult to say which one of these was developed first because in India according to the Indian Archaeologists bronze and iron have an overlapping growth. Dube and Prakash(1970) have studied the analysis of the ancient Harappan bronze objects and they have concluded that these alloys of Cu+Sn were not a result of chance intermixing but designed to develop certain specific properties. Biswas(1981) has reviewed *Rasa Ratna Samuccaya* and noted that the alloy of two metals were called *Durmela lohadvayametañaśca* if the additives were incompatible otherwise it was known as *dvandvana*. The process of addition to the liquid metal was known as *Niravapana*, and an alloy containing five metals was called *Pañcaloha* or *Vartaloha*. Many specific alloys have been given a separate name such as brass was called 'Suvarnaka' and Cu-Pb alloy *Sulvanage*. The objective of alloying could have been one or more of the following:

(i) To produce alloys having similar colour and lusture as Gold, for example 'Suvarnaka' or brass.

(ii) Improvement in the physical properties such as strength, hardness etc.

(iii) Improvement in hot and cold workability.

(iv) To produce alloys having lower melting point and better castability.

(v) To produce alloys having capacity to join two metallic components such as solder alloy etc.

(vi) To produce a cheaper metal and reduce the consumption of precious metal.

(vii) to produce alloys having specific properties such as zinc alloy used for producing 'Bidri' ware.

(viii) To produce coinage metal of specific composition from security point of view and to prevent production of counterfeit currency.

(ix) To produce Fe-C alloys of variety of compositions which could be given a variety of thermo-mechanical treatment to develop desired properties in the object.

The first man made alloy might have been produced by co- reduction of mixed ore minerals such as in the case of production of bronze and brass. The techniques applied for producing some of the important alloys in ancient India are being discussed below.

(i) Gold Alloys

Naturally occurring 'electrum' i.e. Au-Ag alloy was known to Harappan people but in latter period Au-Ag alloys (45-to 90% Au) were deliberately prepared to obtain a variety of colours and shades in the Gold ornaments and other domestic as well as decoration pieces. Today it is known that Au-Ag form a complete range of binary solid solution with lowering in the melting point of the alloy. Addition of Silver also increases the hardness and wear resistance of the alloy.

Similarly copper was added to the gold to impart hardness and better strength as well as more reddish colour to the metal. Au- Cu binary alloy system is characterised by the formation of Eutectic at 20% Cu, having a M.P. of 889°C. In recent years detailed studies of the binary, ternary and even quaternary alloy systems have been studied and published. The details of the binary alloy systems can be found in the book by Hansen(1958).

Since, in ancient times such information was not available, the development of critical alloy compositions must have been achieved by keen observation and long practice, and their secret must have been closely guarded.

(ii) Silver Alloy

As described earlier while Gold was liked for its highly appealing Golden Sun like colour, Silver was recognised for its cool white appearance similar to that of Moon. Silver utensils were very common in wealthy household because they are resistant to the attack of organic acids and alkalies and all kind of food could be prepared and kept in it for many hours. Silver jewellery had its own attraction for dark coloured Indian women.

In latter period with the development of coins instead of barter system of trade (700 B.C.) Silver coins were made from Ag- Cu binary and Au-Ag-Cu ternary alloys. Bharadwaj (1987) has published recently a very comprehensive paper on a large number of these alloys used in Numismatics. Silver coin '*Rūpa*' has been specified to be made of 'Sarametal' containing 11 part Ag, 4 part Cu and 1 part of Fe and Pb etc. This clearly indicates that the alloys were purposely made by mixing the pure metals in a definite proportion. At that time no method of chemical analysis or metallography was available, even then the composition controls in a very narrow limit was maintained as revealed by the chemical analysis off our hoards of silver coins done by Prasad and the study of silver coins from Rajghat and Gupta period done by Saran (1989).

The Silver coins from Gupta period has been found to contain 27 to 28% Cu i.e. corresponding to the near Eutectic composition of the alloy. As shown by Ag-Cu phase diagram in *Fig. 45* the Eutectic alloy (Ag-Cu) containing 28.4% Cu has a melting point of 779°C only i.e. much lower than any of these pure metals. Kautilya's *Arthaśāstra* describes in great detail the process of manufacture of these

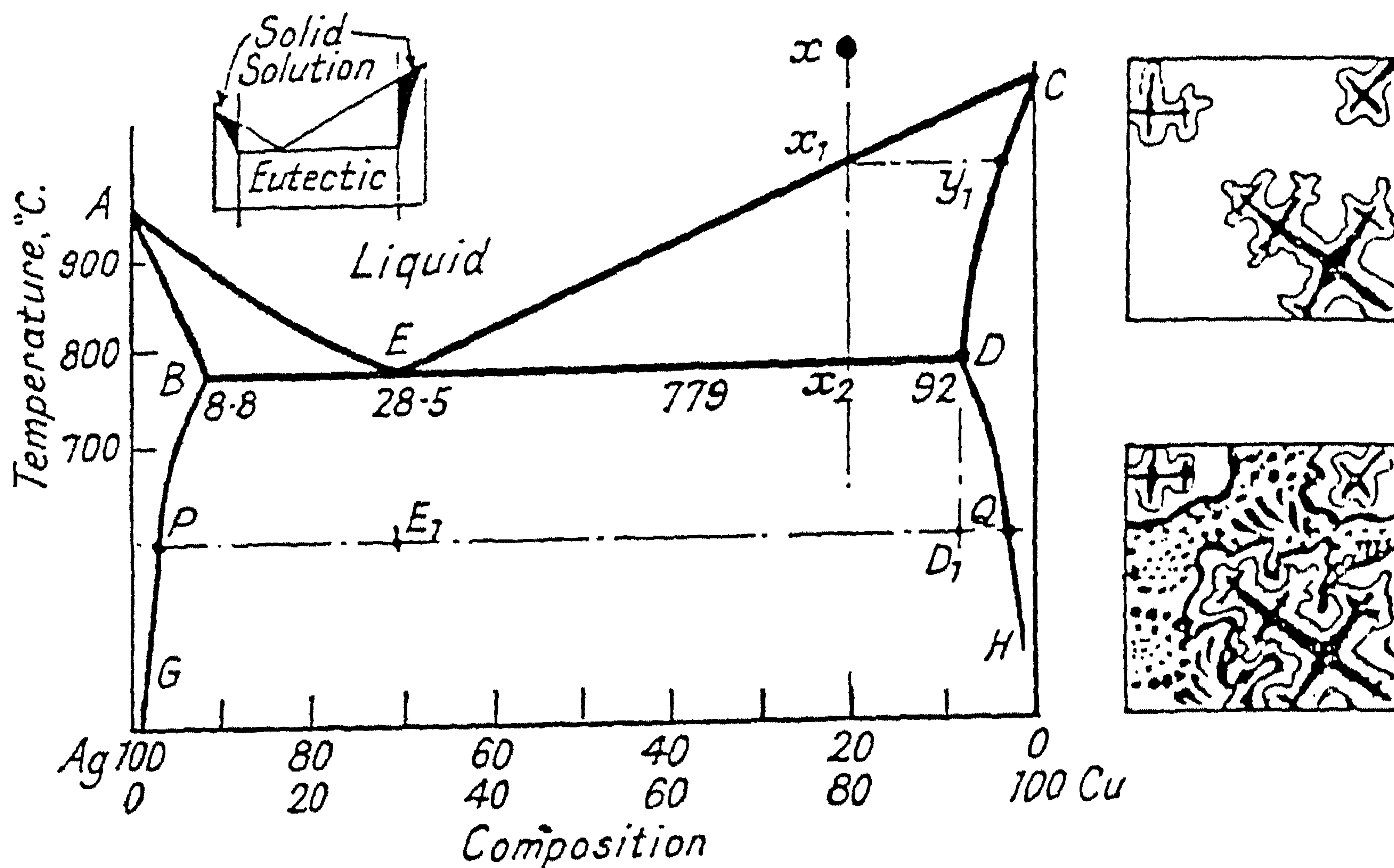


Fig. 45. Ag-Cu alloy phase diagram

alloys and the techniques applied for minting coins which used to have a definite weight. In the beginning these coins were square in shape and their weight was controlled by cutting the required piece of metal from one corner. When the minting of circular coin was begun its weight was controlled by taking a weighed quantity of the alloy and punching out dimensionally controlled coins having the desired punch marks. The study of the punch marks on ancient coins have revealed high level of craftsmanship in the preparation of punching dies. The study of coins of the medieval and latter period have indicated the use of rolled sheet of controlled thickness.

(iii) Copper Base Alloys

Bronze (Cu-Sn) : Besides the invention of Cu-As alloys, which were not very common in ancient India, bronze is the next copper base alloy acclaiming to have World wide revolution in the metals technology which gave a fresh self-defending power to human race and a boost to the cultural heritage. This alloy gained its popularity owing to its golden colour and added edge hardness in as cast condition (200-250 B.H.N.). Bronze is basically a cast alloy having 0 to 20% Sn in copper, to which Pb, Zn, and Ni are also added either as tramp element or purposely to change its properties. *Fig. 46* shows the binary phase diagram of Cu-Sn alloy which indicates a maximum solid solubility of Sn as 15% at 798°C. On solidification the solubility decreases precipitating out Cu- Sn compound which imparts hardness to the alloy. The chemical analysis of the ancient bronze objects have shown a variety of compositions all falling within the above range and having a cast structure. This reveals that manufacture of designed castings and their molding technology was already fully developed in the bronze age or even earlier.

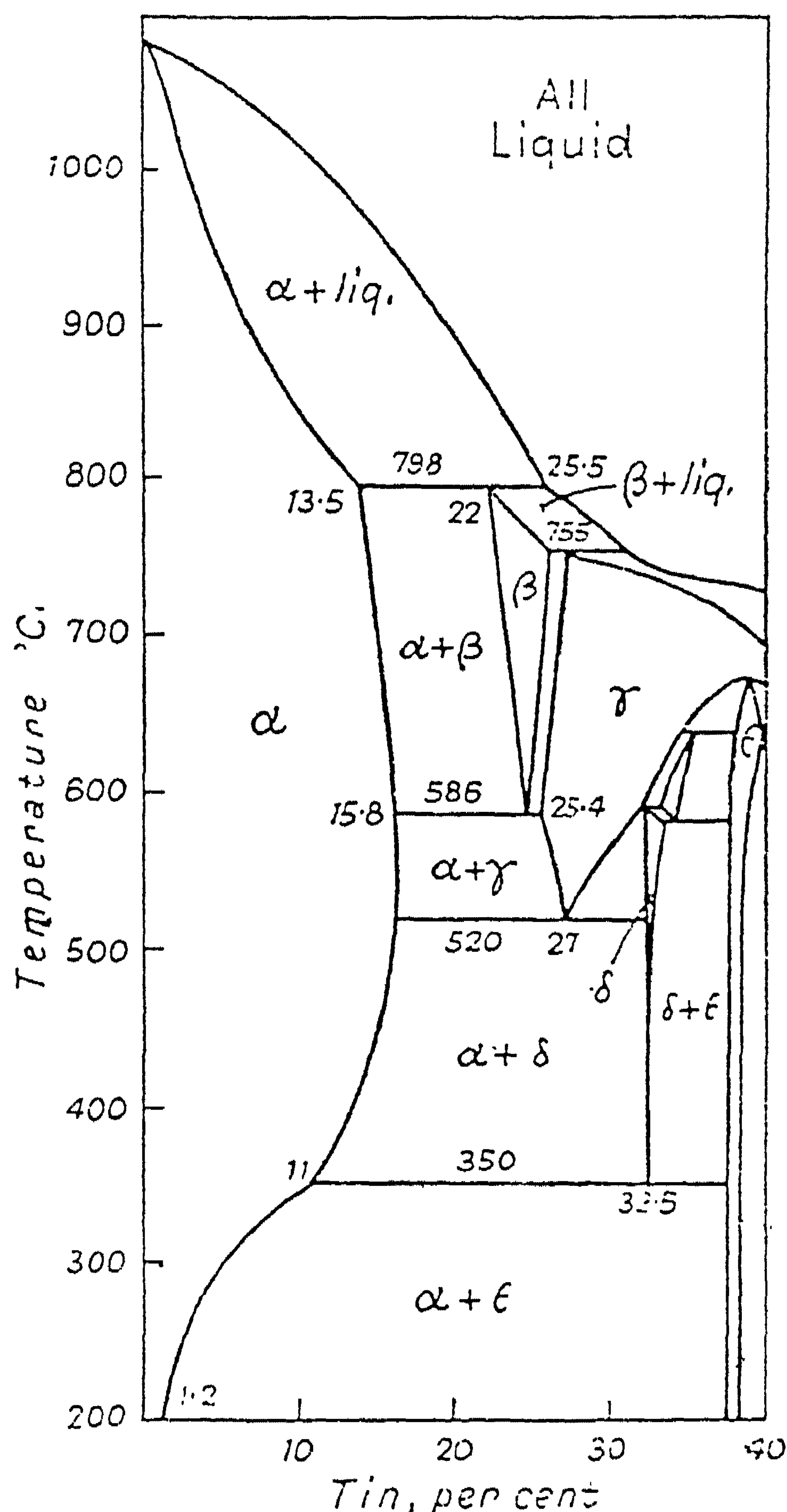


Fig. 46. Copper rich side of the Cu-Sn alloy phase diagram

So far as the availability of tin ore in India is concerned only very lean ore (Casseterite) is found in Chota Nagpur (M.P.) where the tribal craftsmen of Bastar area are still engaged in producing bronze metal and its castings using the age old lost wax process. The popularity and the massivity of the use of bronze alloys suggest that either the ore or metallic tin was brought from Burma or Malaya with which India had very close trade relations. The cast bronze weapons have very hard but brittle nature and these cannot be generally hot or cold worked. The edge of the cast weapon was sharpened by grinding and no heat-treatment was given because the general hardening treatment viz. solutionizing at high temperature and quenching will decrease the hardness due to the increase in the amount of retained solid solution. In order to increase the hardness, solutionizing treatment has to be followed by precipitation hardening and the metallographic studies of bronze objects have not revealed use of such knowledge.

Cu-Zn Alloys : The oldest brass artifact to be found is a cup in the possession of the Iranian king Derius' dating back to 522 to 486 B.C. This cup had a colour like Gold but from it a foul smell used to arise. Fores (1964) has written that most probably this cup was made in India. The famous Chinese traveller Hiuen Tsang has written that Indians knew the method of preparing brass from a mixture of copper and Calamine. As described by Beel,S., Hiuen Tsang has mentioned the use of brass castings and sheet metal work in India as early as 7th century A.D. and he has particularly described a brass *'vihar'* (unfinished convent) at Nalanda during the period of Shiladitya (Harshvardhan) whose walls, doors and window-sill all were covered with brass. Ray (1956) has mentioned about brass technology to be imported from China but above evidences clearly indicate that brass was first made in India about 7th century B.C. if not earlier and most probably the technique of its production was carried by Hiuen Tsang to China.

As described by Tylelcote (1976) the first brass could have been made by co-reduction of copper oxide and calamine in a closed crucible but there is higher probability of its production by dissolving zinc vapour in molten copper using a system similar to the vapour distillation, which was known to Indians for a long time *Rasa Ratna Samuccaya*. Such a system has been described also in Chinese literature as shown in *Fig 47*. *Fig 48* shows the copper rich part of the Cu-Zn binary

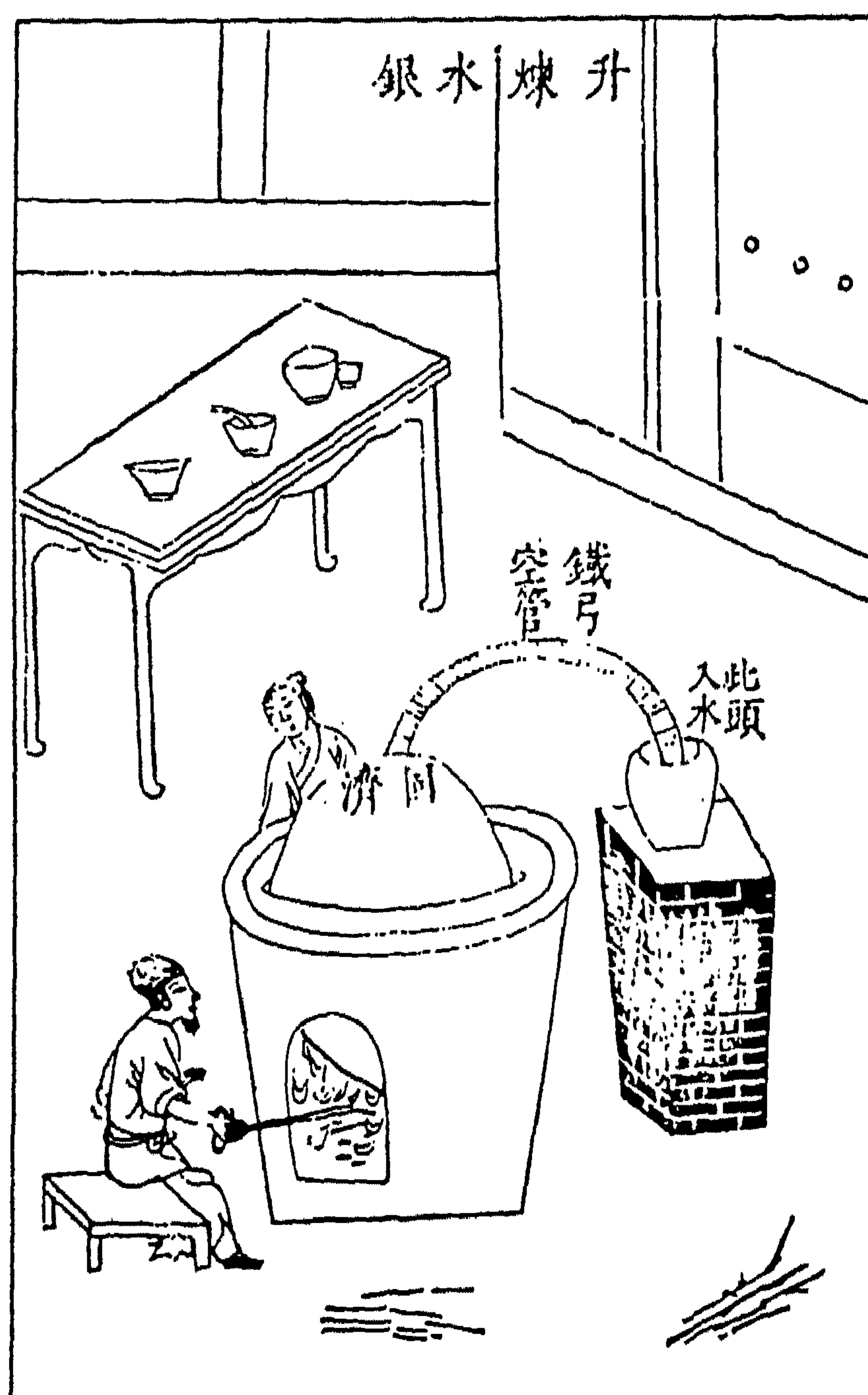


Fig. 47. Chinese system of production of brass using a bent tube for the conduction of zinc vapour to the crucible containing molten copper

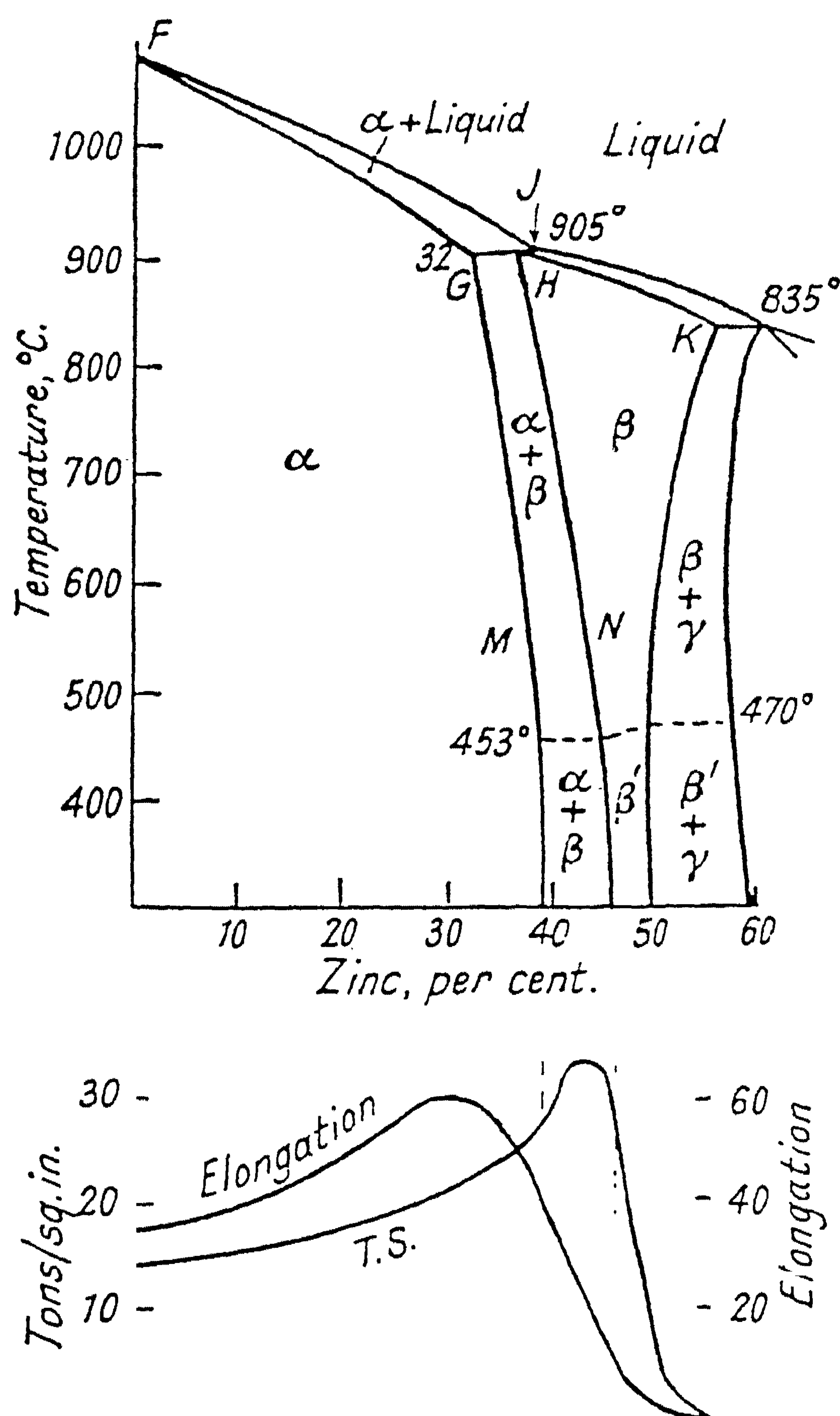


Fig. 48. Copper rich part of the Cu-Zn phase diagram and change in mechanical properties

phase diagram which indicates that upto 39 wt.% Zn forms a solid solution with Cu (-brass).

The alloys in this range contain Zn from 5 to 20% and they can be cast and cold or hot worked, and these have a very low M.P. i.e. only 750°C. Brasses having higher Zn content have been rarely reported from ancient sources. These are called α- β brass and they can be generally used only in as cast condition. These alloys are characterised by their Gold like colour and capacity to take very shining polish. These could be easily gilded with Gold. On storage of alkalies or food having organic acids the food gets stale in short time and the surface of the pot tarnishes black, giving out foul smell. This metal is also subjected to a special type of corrosion on storage i.e. Dezincification. Many brass objects found during archaeological excavations have suffered from this type of corrosion and got

converted into a lump of copper powder, due to the loss of Zn with time. In RRS two type of brass have been mentioned 'Ritikā' and 'Kakatuṇḍi': on coming in contact with hot lemon juice (Kañjikā) Ritikā used to turn copper red whereas Kakatundi used to become black.

Brasses have been the alloy of the more civilised agriculture based communical culture and it had found extensive domestic uses. Brasses containing 20 to 30% Zn have very good ductility and they can be shaped by any metal craft technique. In this period more refined technique of preparation of these alloy were developed by direct alloying as described by Kautilya in his *Arthasáśtra* and Saraswati (1936). In the Chola period this alloy has been extensively used for production of beautiful idols and icons using 'Cire-perdue' casting technique.

Brass has also been used as *Puṭṭi* (*Vajrasaṅghaṭṭ*) or soldering alloy. Saraswati has mentioned a typical composition made by melting 8 parts of lead mixed with two parts of bell metal (bronze) and one part of brass. During the Medieval and latter period brass industry has developed many folds and even today it is in great demand, although today stainless steel utensils are replacing brass utensils at a very fast rate.

(iv) Iron-Carbon Alloys

With the discovery of the effect of carbon on the properties of iron has begun the real industrial and cultural revolution in this World. The solid state of Iron-carbon phase diagram has been already shown and the effect of 'C' on the proportion of Ferrite and cementite phases in the alloy has been already discussed. Ancient Indian iron craftsmen had learnt about the role of carbon in increasing the strength and hardness of iron even as early as Vedic period if not earlier and by 8th to 12th century A.D. they were capable of producing a variety of Iron- carbon alloys as classified in *Fig. 32*. *Yuktikalpataru* a Sanskrit alchemical literature of 11 century A.D. mentions the relative properties of iron-carbon alloys as produced in different regions of India and the resulting properties of the alloy produced either due to minute difference in the smelting practice or presence of some other minor alloying elements. The description given in this literature is quoted below:

(i) *Crouñca* - iron supposed to be two times better than *Sāmānya* (probably *Muṇḍa Loha*).

(ii) *Kaliṅga* (Orissa) - iron 8 times better than Crounca iron.

(iii) *Bhadra* iron - 10 times better than *Kaliṅga* iron.

(iv) *Vajra* - 1000 times better than *Bhadra* iron.

(v) *Paṇḍi* - 100 times better than *Bhadra* iron.

(vi) *Niraṅga* - 10 times better than *Bhadra* iron.

(vii) *Kāntā* - one billion times as good as *Niraṅga* iron.

The Indian blacksmiths had also learnt the art of heat- treatment as discussed later and their product was in great demand throughout the World. Alexander had asked 30 Seers of Indian steel as present from King Porous.

Once the strength and properties of iron and steel were known the use of non-ferrous metals and alloys were confined only to domestic and other areas of

human needs. The Indian metal craft was flourishing during the Mughal period but after the spread of the British Empire and the restrictions imposed by them in the form of production taxes and ban on export this industry died down. This disappearance of the ancient technology during 17th to 19th century was supported by the discovery of new alchemical principles and development of new industrial process of metal production in Europe. In the 20th century the condition has become so worst that the memory of ancient glory remained only in the form of stories narrated by old men and after the independence in 1947 India had to borrow the modern technology from western countries to set up steel plants and other industries.

(v) Other Alloys

Besides the above mentioned alloys many other binary and multi-component alloy compositions such as *Pañca loha* and *Aṣṭadhātu* were known to Indian craftsmen. These alloys were used for specialised purposes and their production technology were very closely guarded. Alloys or Ag-Cu-Sn etc. Sn-Pb alloy or Sn-Pb-Sb or special zinc alloy were used for producing coins, type metal, tinning alloy and Bidri ware. Amalgam or Hg-Au was used for Gold coating on brass and copper objects. Fine wires of Au, Ag and Au-Ag alloys were drawn to prepare jari thread used in a variety of embroidered silk and brocade. Silver alloy filegree ornament manufacturing craft of Orissa is famous even today.

Metal Casting Technology

Generally it is believed that the first metal artifact must have been produced by cold working i.e. forging, virgin metal nuggets found in nature but the early knowledge of the art of metal casting also cannot be denied. The description of this craft in the *Ṛgveda* and *Yajurveda* is a clear indication of its knowledge in that period. It is definite that the idea of shaping metal by handling it in molten condition must have originated from the observation of the flow characteristics of molten Gold, Silver or Copper and their capacity to take the shape of the channel on resolidification. Even some of the earlier-square coins have revealed the cast dendritic structure confirming their manufacture by casting technique. These coins belonging to 4th to 7th century B.C. were most probably made by first casting molten metal in open channels and then hammering it flat before cutting the strip into square sections of uniform size and weight.

The exact weight was obtained by cutting the metal from the corner and finally the coin was punch marked. *Caraka Saṃhitā* has mentioned the process of making sculptures and idols of Au, Ag, Cu, Sn etc. by the 'Cire perdue' process.

From the study of the bronze statue of the dancing girl it is obvious that metal casting technology had reached its perfection during this period (2500 to 3000 B.C.). The idea of making metal statues and idols probably arose from the manufacture of terra-cotta toys and the method adopted for their mass manufacture using a baked clay die, made into two halves. Archaeological evidences so far collected have indicated that after learning the process of melting metal into crucibles and its casting into earthen channels man started using preshaped molds

of clay or cavities made in sand stone or soap stone pieces, which gave rise to the first concept of die-casting. Later-on man must have learnt to make clay or wooden pattern and to produce a replica of the same by making consumable molds in sand and clay mixtures leading to the development of the modern molding method and foundry technology.

'Madhuchib-bhist' or 'Cire Perdue' process is a refined technique where pattern of the desired shape is made from bee's wax and then a mold is prepared by applying coatings of prepared clay slurry on it. Later-on when the refractory clay slurry has dried the wax is removed by baking the refractory shell. Thus only one casting could be made from one wax pattern. Before casting the molten metal the refractory shell was generally embedded in a box filled with the sand clay mixture for further support to the refractory wall. After pouring the metal and its solidification the mold was carefully broken to take out the metal casting which was given finishing touch by filing, chiselling, engraving and polishing etc. Saraswati has given a vivid description of this ancient technology and it has been refined during Calukya dynasty to produce innumerable brass and bronze pieces of art and idols of Gods and Goddesses which have kept the World wondering about the rich technological heritage of India as reviewed and described by Pal. (1983) Shama Shastry (vide *Arthaśāstra* of Kautilya) has referred in two books on this ancient art of metal casting viz. *Manasollāsa* and *Abhilasita Cintāmaṇi* of 12th century A.D., which give a detailed account of the method of preparation of wax pattern and slurry coating, provision of sprue, riser and runner etc. The composition of the clay slurry coating as given by them consisted of clay mixed with charred rice husk and sodium chloride all mixed in a definite proportion and finely ground. Recently Kumar and Saxena et al. have prepared a detailed report on the lost-wax technique currently being used by the tribals of Bastar for producing various brass and bronze objects. *Fig. 49* shows a bronze chandelier cast by this process in one piece where even the chain links were also cast along with the other parts in one mold. Indian and foreign museums are full of such intricate castings produced by the Indian craftsmen in the past. *Fig. 50* shows the five steps of the traditional process of making brass and bronze icons by this process as practiced even today in South India.

Fig. 51 shows the famous Icon of Lord Nataraja made by this process. Today this process has been adopted by the modern foundries for the mass production of precision castings of brass, bronze and even steel.

Beel,S.,has quoted from the travel documents of Hiuen Tsang, that at Varanasi a copper icon of Maheshwar Deo having a height of 3000 mm was found. Kulkarni (1989) has written that from Sangharam of Bhagalpur distt. a 2286 mm high copper statue (11th century A.D.) has been obtained which was made by casting in parts and then rivetting them together with the help of iron strips. Joshi (1970) has described the use of this technology two decades back for making a 1820 mm high statue of Lord Hanuman (weight 350 Kg.) by casting it in parts and then brazing them together. The study of the ancient brass and bronze icons have revealed that ancient craftsmen were capable of producing solid as well as hollow castings, which were probably made by pouring out the remaining liquid metal after partial solidification has taken place near the mold wall.



Fig. 49. Photograph of a brass chandelier of 8 century A.D. showing the chain cast in one piece

Another example of the skill of the ancient Indian is the process of casting of bronze coins. For producing these cast coin, as described by Sharma and Bhardwaj (1987) and Mukherjee and Lee (1988), the impression of a number of coins was made on Terracotta disks as shown in *Fig. 52* with a central sprue connected to all the molds by small runners. The cope and drag of these disks were stacked to form a 'Jhari' type mold. This stack was carefully packed from all the sides in a sand molding box and then molten metal was poured through the central sprue. As the

Fig. 50. Five steps of the traditional method of casting brass and bronze idols in South India using 'cire perdue' process

molten metal entered the mold the air from these cavities escaped through suitably provided air vents. Thus a large number of bronze coins of consistent composition, size and weight were cast in one mold and taken out after solidification. The risers and runners were broken away and the finished coins were sent to the mint. This technique of casting large number of small castings in one single mold is also being used with certain modification even today.

During the Mughal period the casting technology was much developed and it was used for casting huge Guns like Malikai Maidan. The mould for this heavy and beautifully designed gun was prepared below the ground level by using moulding sand mixture and sweep moulding process. A solid core prepared from rice paddy, sand and clay mixture or sand and molasses mixture was first dried and baked and then fixed in the centre of the mould to make the bore hole of the gun. In the absence of heavy crane and machinery for handling such large amount of molten bronze the melting furnace was constructed at a higher level. The molten metal was melted in a large shaft or crucible prepared insitu, and when it had reached the desired composition and fluidity the molten metal was poured into the mould by preparing a channel connecting the crucible to the mould and piercing a hole in the crucible wall. After the casting had solidified over a period of few days the mold was broken

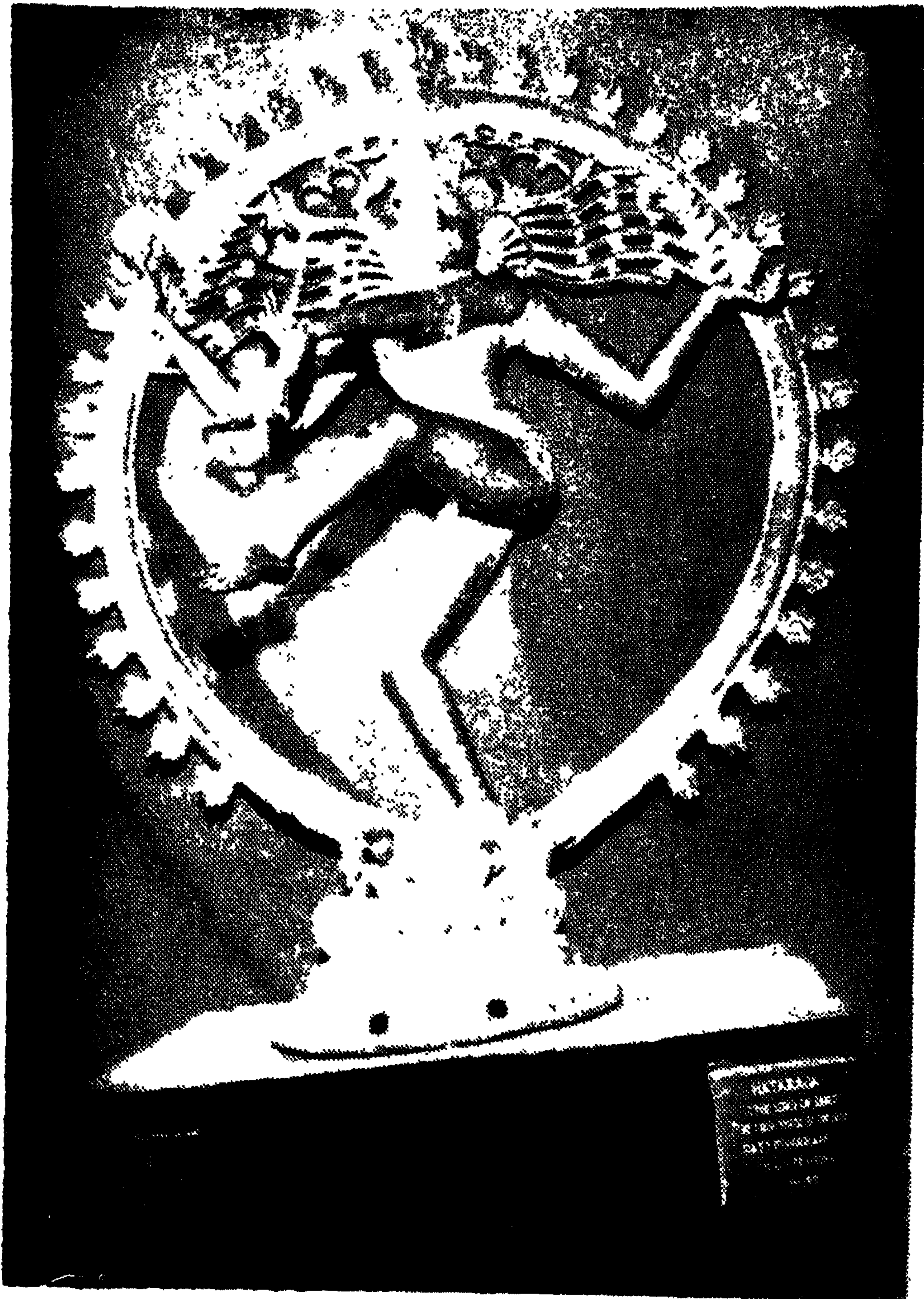


Fig. 51. A Bronze casting of Lord Naṭarāja made by 'cire perdue' process

to take out the casting and finish it by cleaning, chiselling and polishing. In a like manner huge cannon balls were cast either in non-ferrous metals or cast iron. This industry has also faced a set back during the British Rule.

Thermo-Mechanical Treatment

According to Tylecote (1976) the beginning of the craft of cold working of metals might have begun with the discovery of native Gold or Copper and discovery of their deformation when hammered. The lithic people might have hammered these nuggests with stone to break away chips having sharp edge, as in the case of stone tools, and to their surprise they might have discovered that these nuggets could be deformed by hammering. This might have lead to the manufacture of some simple tools and weapons by cold working, and sharpening of the edges by grinding on stoneslab.

The other possibility is that the initial metallic nuggets might have been brittle due to the presence of oxide and sulphide inclusions or separation of some other phase on cleavage planes such as separation of Ni on Widmannstat planes in meteoric iron. Such nuggets will break into pieces having sharp edges. In such a

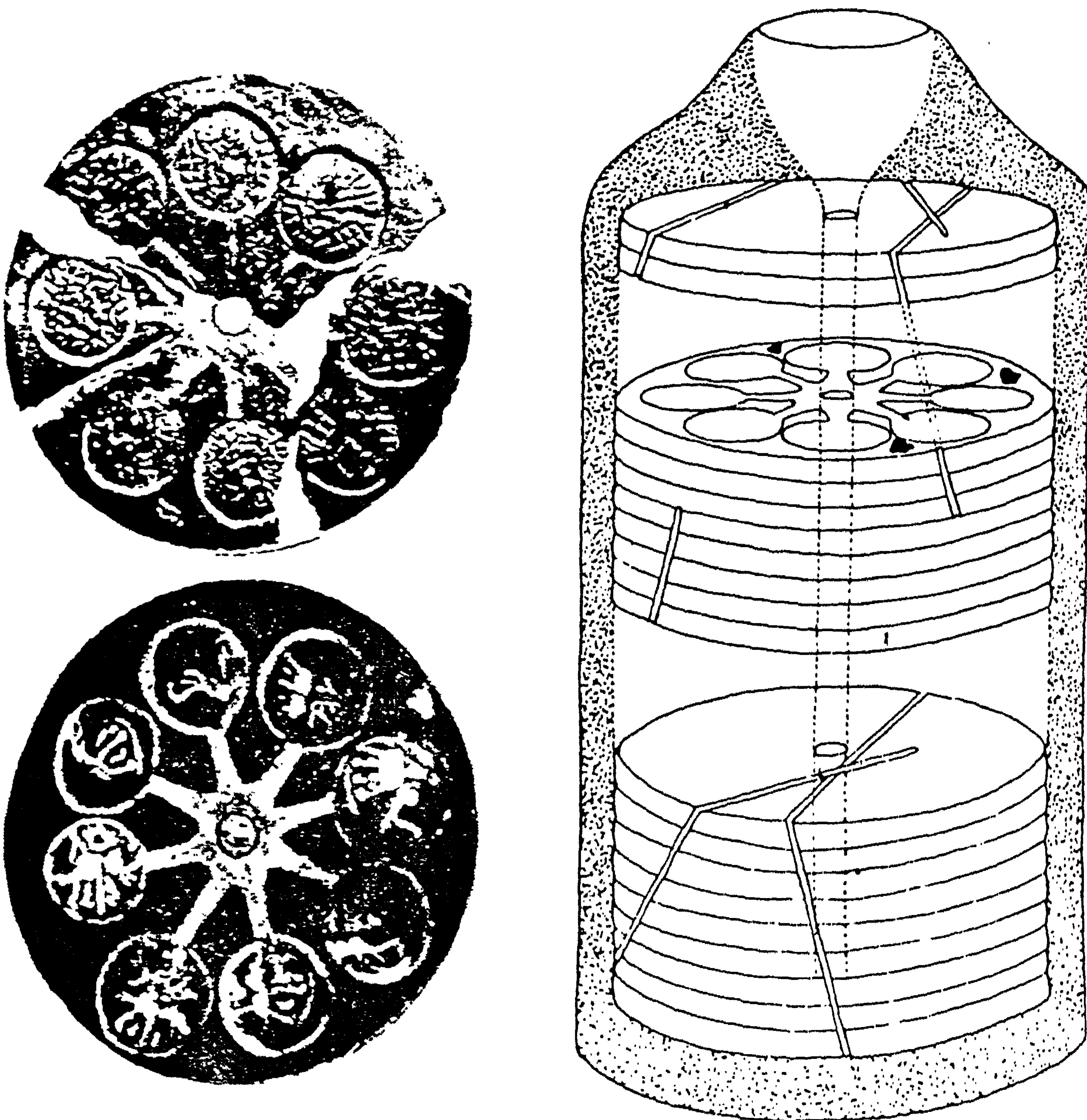


Fig. 52. Terracota mould disks for coins and their assembly ready for casting

case the concept of cold working metals may be associated with the casting technology because, according to Tylecote some of the early copper objects (3000 B.C.) have been found to show the structure of annealed and recrystalised metal.

So far as India is concerned the technology of shaping of metals by cold working can be dated back to the Vedic period if not earlier. The 'Rīchas' in *Fig.4* clearly indicates the acquaintance of ancient Indians with the use of steam power.

This is possible only when they had gained high degree of knowledge about the ductility of metals like copper and iron and the skill to give them the desired shape by hot and cold working. In Vedas there are also descriptions of the development and use of metallic war weapons.

There is ample evidence that during the period of Indus Valley civilization Indian craftsmen had gained high level of knowledge regarding the effect of cold working of metals and their recovery on annealing and perhaps they also knew the

improvements achieved by hot working of metals. Following is a short account of some of the metal forming technology and the skill achieved by the ancient Indians in improving the properties by thermal treatments such as annealing, hardening and tempering of metals.

(i) *Embossing and Engraving* - The art of preparing metallic sheets by cold working of Gold, Silver and other non-ferrous alloys and their shaping by embossing to produce various pots and pans as well as jewellery has been probably the second phase of metal working technology. The art of engraving on metals to produce beautiful designs of flora and fauna might have been a continuation of the traditions of wood carving and knowledge of painting. In many cases the wooden panelling and carvings have been inlayed with fine gold and silver wires, pearls, shells and pieces of mirrors etc. to produce master-pieces giving grandeur to the life style of Kings, Queens and wealthy people. Covering the wooden pannelling with Gold, Silver, Copper and Brass sheets and carving beautiful designs on them by embossing and engraving have been in practice and artisans must have used very fine and precisely designed tools mostly made of iron and steel.

The study of the ancient objects of art and socio-cultural pattern indicate that these ancient craft were highly specialised and disciples were trained from the very childhood in their traditional craft. For example while the iron and steel tools were made by blacksmiths the Gold and Silver work was done by 'Sonars' and sheet metal work was done by 'Thatheras'. Thus the skill was passed on from one generation to the other and sometimes lost due to the natural calamity or other reasons.

(ii) *Wire Drawing and Jari Work* - Wire drawing craft has been known in India both for the manufacture of Gold and Silver Jari as well as fine wire of bronze, brass, iron and steel used in the string musical instruments like sitar, sarangi, veena etc. The art of jari making and production of 'Brocade' and embroidery silk has been known atleast for the past 4000 years. The silk cloth and Brocade of India had been as famous in the world as the Chinese silk. The process of manufacture of jari thread consists of first making a fine wire of Gold, Silver or their alloy and then flattening them to obtain thin strips having highly polished and shining surface. These strips were then wound around silk and cotton thread to produce jari thread.

The technique of wire drawing using hardened steel dies or die plates having hair like fine holes has been in use for ages and even today the jari manufacturers of Varanasi and Gujarat are skilled in producing their own dies instead of using the modern diamond dies and machines. The wire manufacturers had the idea of work hardening and annealing to soften the material by recrystallization and grain growth.

The starting material for this industry was a rod of gold or silver about 10 mm in diameter and 100 to 200 mm in length. This was first cold worked to produce a thinner section having 3 to 5 mm diameter and then it was annealed and converted into fine wire by drawing through a sequence of die holes having smaller and smaller diameter. The process was accompanied by intermittent annealing in a slow heat produced by burning cow dung cakes. The final thin wire was flattened by rolling it between a set of highly polished rolls (50 to 100 mm diam.) having mirror like surface finish. As the thin wire was flattened by these rolls the shining surface

finish was transferred to the Gold and Silver strip which was finally wound around cotton or silk thread. A large collection of ancient jari craft and the fine pieces of 'Brocade', woven and embroidered silk pieces are being preserved in Bharat Kala Bhawan Museum of Banaras Hindu University and in other National Museums.

The manufacture of variety of string musical instruments of Indian origin required wires of various diameters produced from very precisely controlled composition. This industry also desired metals and alloys to be produced free of non-metallic inclusions so that long wire could be drawn without its breaking. The Indian craftsmen were not only skilled smelters but also alloy makers as well as skilled in fluxing technology to produce metal ingots, even of steel, free from even the micro size non-metallic inclusions.

The manufacture of Fe-C alloy i.e. steel wire required skill of very high level and precise experience about the thermomechanical behaviour of these alloys, their work hardening properties as well as annealing behaviour all learnt by time consuming experience was transferred from Master Craftsman to his chosen disciples.

(iii) *Bidri Work* - This craft of producing utensils and decorative objects, jewel boxes etc. decorated with beautiful designs produced by inlaying Gold and Silver wires on the surface of the object has been a speciality of the 'Bidar' tribe of Hyderabad. In this process as described by Mahamud (1988) at first a zinc base casting of the object is made using lostwax or any other molding and metal casting technique. The composition of the special alloy consists of 16 parts of copper, 4 parts of lead, 2 parts of tin and 112 parts of zinc. The casting is cleaned and its surface is smoothened and polished and then its surface is bleached by dipping the object in a solution containing Sal Ammonia, Saltpeter, Common Salt, Blue Vitriol and Resin mixed in a definite proportion known to the craftsman. This treatment produced a metal ware with grey black finish.

After this treatment the surface of the object is engraved with beautiful designs of fauna and flora and inlayed with Gold and Silver wire. Finally the inlayed surface is carefully cleaned and buffed to give a shinning finish.

(iv) *Gilding* - With the increasing demand of gold objects and the development of Alchemical Principles Indian Craftsman had learnt about the amalgamation property of Mercury with copper, gold, silver and their alloys and this led to the introduction of a new technique of extraction of the precious metals as well as their coating or plating on the surface of cheaper base metals and non- ferrous alloys. This technique of coating or 'Gilding' consisted of cleaning the surface of the base metal and then rubbing the Au-Hg or Ag-Hg amalgam on the surface till all the Hg was evaporated away leaving a coating of Au or Ag or their alloy on the surface. Such coatings were long lasting and maintained a highly shinning golden or silvery lustre on the cheaper base metal objects.

(v) *Gold and Silver Foil Technology* - Some times gold and Silver foils were also applied to the surface to obtain a thicker coating. These foils were produced by putting a small piece of the metal in between two layers of Chamoi leather and beating it till a very tin foil of the metal was produced. This thin foil was lifted on paper, to give backing support and stored till applied to the surface. Gold and silver

foils were also used to decorate food stuff and pan etc. The Ayurvedic medicinal system mentions the beneficial therapeutic use of these foils and curing some of the diseases.

(v) *Smithy Craft in Iron and Steel* - From the study of the archae ological iron objects there remains no doubt that ancient blacksmiths had attained very high level of skill in cold and hot working and sheet metal forming of wrought iron and iron-carbon alloys. They were also aware of the better metal workability of Fe-C alloys in hot condition i.e. greater than 900°C, and that two pieces of iron could be force welded in the white hot condition (~1100°C).

The examination of some of the ancient objects such as the iron cannon shown in *Fig 53* show a high level of skill and understanding of these processes.

The forging of the Dhar Iron Pillar has shown a technological process of manufacturing somewhat similar to that used for the manufacture of the iron cannon. Prakash (1989-90) has studied and analysed the technique of manufacture of the Dhar Iron Pillar. *Fig. 54* shows a schematic drawing giving details of the joint of two iron blocks by the use of a tapered pin as envisaged by Prakash. The joint of the two blocks has been reinforced by butt welding of iron plates from all the sides. *Fig. 55* shows a photograph of the top of the Delhi Iron Pillar and this also shows the signs of hot fitting of a square ring on the circular shaft of the pillar. In the centre of the pillar there is a square cavity supposed to be used for fixing

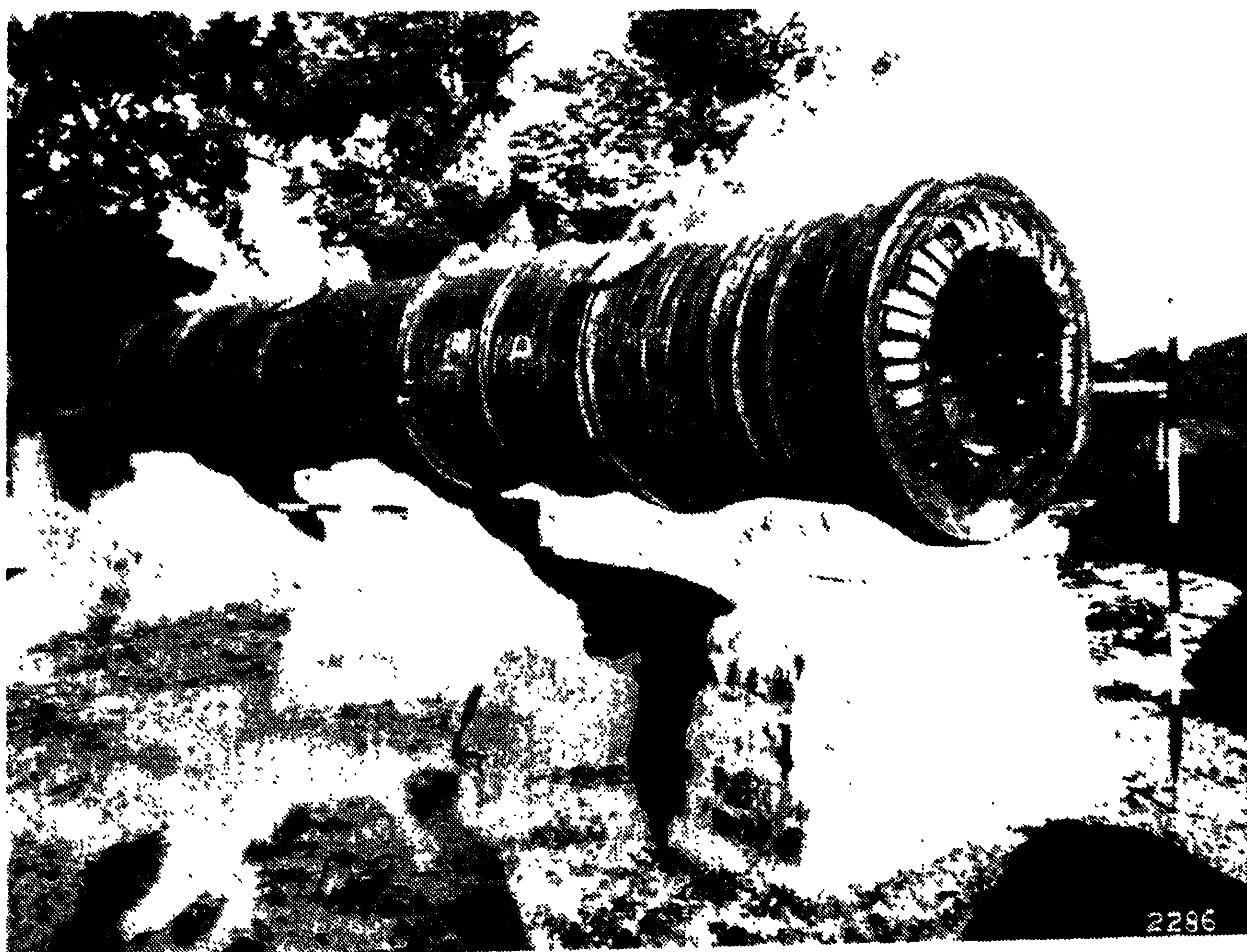


Fig. 53. Photograph of an early iron cannon (Tanjor) made by fixing iron pieces inside a number of iron rings

either a sculpture of 'Garuda' or the 'Lion Emblem' of 'Ashoka'. Bindal (1988-89) has reported the presence of sponginess at the centre of the Delhi pillar at certain heights. This may be the result of the tapered pin joint in this pillar similar to that proposed in the Dhar pillar. Unfortunately no documented evidence of remains of

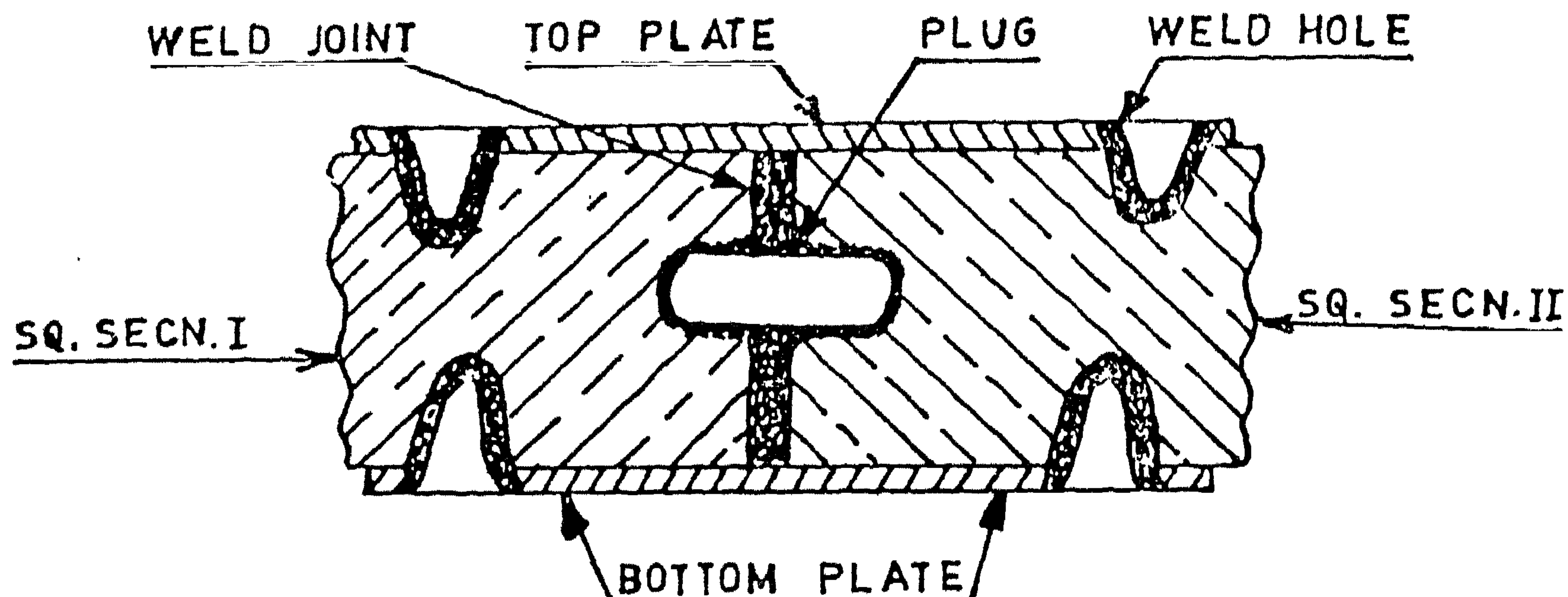


Fig. 54. Drawing shows the probable method of joining two iron blocks in Dhar iron pillar



Fig. 55. Photograph shows the fixing of a massive iron square ring to form the ornamented top of Delhi's iron pillar

the site of their production has been traced so far and in the absence of these the iron pillars of Delhi, Dhar and beams of Konark temple need a detailed metallurgical study to reveal the exact process of their manufacture. Bonner et al. (1972), have translated the account book for the manufacture of the iron beams of the Sun temple of Konark, but the details of the operations and process of their manufacture mentioned in this document are insufficient to draw a definite conclusion.

In order to appreciate the knowledge of the ancient smiths it is essential that we make reference to the Fe-C diagram shown in *Fig. 56*. This figure shows the change in structure of five different Fe-C alloys as attained after normal cooling. This diagram also shows various temperature ranges to which the Fe-C alloy should be heated to carry out different thermomechanical treatment like forging, forge welding, annealing and spherodizing etc. The ancient blacksmiths were ignorant about such phase diagram but they had gained knowledge by experience and they understood the effect of carbon on properties of iron as depicted by the classification and proved by the manufacture of many massive iron objects which have no parallel in the world.

The world famous 'Wootz' steel swords were made by forge welding small rods of wrought iron and steel cakes in a very narrow range of temperature and then giving it the traditional 'watering' treatment. This must have been possible only by the extensive knowledge about the hot workability of various iron carbon alloys. The cast structure of high carbon hyper eutectoid steel consists of massive platelets of Cementite separating out on Widmanstatten planes and Ledeburite and it is extremely difficult to hot forge it without cracking. Yater (1983,1983-84) and Verhoevens (1987) have discussed the technicalities of forging such steels to produce Damascus swords. The process generally consisted of careful forging of the ingot in cherry red hot (~750^{o}C) condition followed by spherodizing treatment to convert the Cementite plates into spherical massive Cementite. This treatment was followed by cold forging of the sharp edge and low temperature annealing (~800^{o}C). The forged sword blade was cleaned and given proper surface finish before it was hardened.

Thus the Indian swords and other war implements were manufactured, by forge welding of a number of 'Wootz' steel ingots or skill fully sandwiching the high carbon steel pieces between wrought iron plates to obtain high carbon edge with flexible wrought iron blade. In some cases the whole blade was made from wrought iron and then the sharp edge was given carburizing treatment before hardening.

(vii) *Heat Treatment* - The ancient blacksmiths had gained very precise knowledge regarding the grain texture of various iron carbon alloys, and they knew that the final hardness achieved on any cutting tools is dependent upon the combined effect of the following five variables :

(a) the carbon content of the alloy

(b) the massivity of cross-sectional thickness of the object,

(c) the final temperature of the object from which it was

quenched (900-1000^{o}C),

(d) The severity of cooling achieved during quenching, and

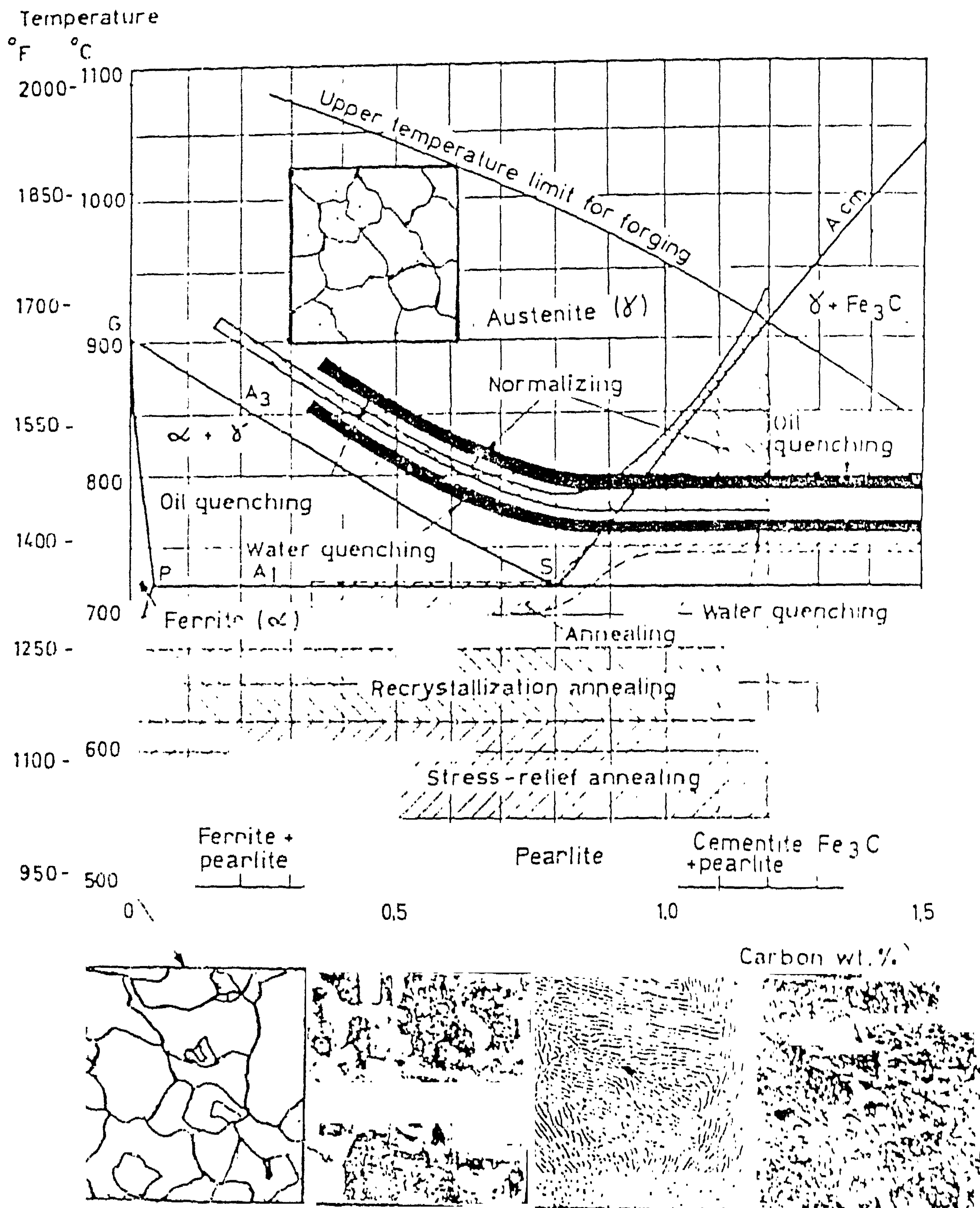


Fig. 56. Fe-C phase diagram showing microstructure of five typical Fe-C alloys and temperature ranges for common thermo-mechanical treatment

(e) Other factors such as control of the phase transformation by arresting the hardening treatment at an intermediate stage.

Prakash (1990) has discussed the effect of these factors on the final hardness obtained and the ancient hardening practice with reference to the modern knowledge of the Time-Temperature and Transformation curves, and hardenability of steels.

The classical Indian heat-treatment given to the steel swords was to heat the blade to red hot condition and then insert the blade from the cutting edge side into

a green trunk of Plantain tree and allow it to cool there. During this process the organic fluid and water present in the cells of the trunk created a cooling rate fast enough to transform the Austenite of the edge into Martensite and in the latter period the dried wood helped in self tempering by acting as heat insulator. This typical heat treatment was called 'watering treatment' and it produced a typical flowery pattern on the sword blade as shown in *Fig. 34*. Recently Rakshit et al. (1991) have experimented on this technique of hardening steels and were successful in developing edge hardness of Rc 45 to 47 with decreasing hardness towards the thicker section of the blade. Archaeological evidence of hardened steel has been found by Ghosh and Chattopadhyaya (1982) dating back to 810 B.C. at Barudih in Bihar.

(viii) *Difference between the Damascusizing and Pattern Welded Structures* -The original structure of the Damascusized or 'watered' sword as shown in Fig 34 has been admired both by the ancient as well as modern metallurgists and every effort has been done to duplicate it. One of the approaches carried out all over Europe is pattern welding of steel pieces of different carbon contents in a large number of different ways to generate a structure similar to that of Damascus sword but so far it has not led to any success. One of the main reasons is the non-availability of Damascus swords for making detailed study of its structure and properties using modern tools and techniques.

As Paisowski (1974) and others have mentioned Belaiew (1921) had the privilege of studying four such blades, and later on others have been quoting his results because even those four swords have been lost. According to the available description the watering pattern on the Damascus sword was developed by etching the surface with a solution containing vitriol, vinegar and many other chemicals,known to the sword manufacturers. After polishing and etching the surface of the sword it was washed, polished and smeared with oil. The study of the watering pattern has shown a structure of dark etching Cementite or Pearlite phase present in a matrix of Ferrite. The heat treatment of pattern welded swords have no doubt produced a variety of etched black and white pattern but they have failed to duplicate the original Damascusizing pattern developed on swords made from 'Wootz' steel. Recently an International Conference 'The Craft of the Blacksmiths' had been organised at Belfast in 1989 and the proceedings edited by Scott and Cleere (1989). At this Conference the archaeometallurgical studies and the experiments conducted on pattern welded steel swords and their heat- treatment has been discussed in great detail.

Tools and Furnaces - The recent discoveries of stone age sites in Indian subcontinent have proved beyond doubt the antiquity of Indian civilization. During the stone age itself the humanoids had learnt the use of simple tools like Axe, Hammer, Chisel, Knife prepared from stones and bones.

The stone axe and other stone age tools found at Jalapur and Soan in Pakistan by Rendell and Dennell (1987) are probably the oldest in India dating back to Sivalik series (17 million year old). With the discovery of native metals these were replaced by tool made of copper, bronze and iron and the era of metal extraction technology was initiated as the ancient Indians gained knowledge of the naturally occurring metallic minerals and the reducing as well as smelting power of charcoal

fire. Some of the iron tools used for mining have been already reported. These tools seem to be very light weight for shaft sinking and excavation of tunnels and galleries through hard stone beds, but these might have been used for digging out the ore minerals from reefs and streak or soft minerals like, Galena, Limonite and Cuprite etc. For breaking the rock bed either the fire setting method or some heavier tools must have been used.

So far as extraction of metals is concerned design of a large variety of pit and shaft furnaces have been already described in the text. In *Rasa Ratna Samuccaya* very precise description of furnaces for various purposes has been given. These furnaces were precisely designed and constructed for specific operation. For example, for making ornaments from silver by Philgree work or for soldering pieces of gold or Silver, jewellers have been using an oil lamp and a tapered brass blow pipe. The desired high temperature at the precise location was developed by blowing air through the blow pipe and diverting the intense flame at the precise spot. It shows that even in the early Vedic period Goldsmiths were aware of the effect of Oxygen blowing on the flame intensity.

Figs 57 and 58 show some of the common metal tools used by smiths for metal working obtained from the excavation site of Taxila dating back to 3rd century B.C. to 5th century A.D. (Marshall, Vol.III, 1951).

Iron smelters had specialised in producing a variety of refractory crucibles for metal smelting and refining which could easily sustain a temperature of 1500°C

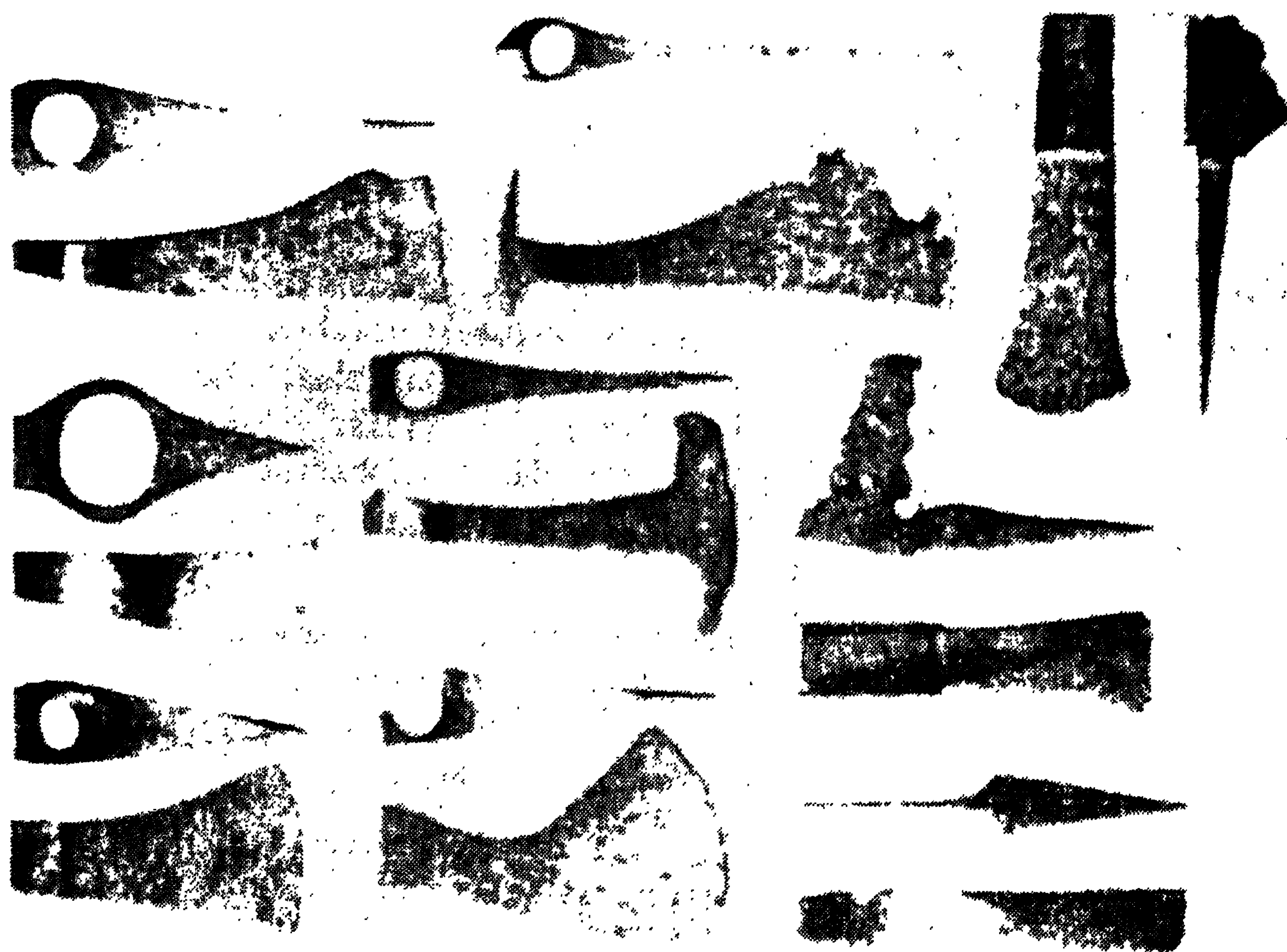


Fig. 57. Some of the smithy tools found at Taxila (3rd century B.C. to 5th century A.D.)



Fig. 58. Some other smithy tools found at the same site

without any significant deformation. These crucibles were used only once and then discarded. Recent mineralogical study of these crucibles have shown the presence of graphitized Silica and Mullite minerals in these crucibles. These minerals were generally developed by the mixture of clay with rice husk and iron oxide etc. and giving a precisely controlled firing treatment. The smelters and smiths had mastered the technique of controlling temperature and atmosphere of the furnaces by the study of colour and control of the air supply.

Metal smiths and Blacksmiths had great skill in manufacturing various objects of non-ferrous metal and they had gained knowledge about the work hardening, recrystallization and grain growth during annealing etc., and they designed furnaces suited for the specific job. While, for annealing copper and brass and other low melting metals only cow dung cake was used as fuel in a 'Ardha Gajaputa' or 'Gajaputa' furnace (1000 cakes), charcoal was used to achieve higher temperature required for annealing of iron. The smithy furnace and the workshop was very simple in the overall out look.

This photograph has been taken by the author during his trip to Bastar in 1981 and it shows the use of a stone anvil for hot forging small iron objects. Mahamud has described the design of a reverberatory type furnace which was being used for a long time in Assam for annealing and probably malleablizing of Fe-C alloys. *Fig.59* shows a drawing of this furnace which is very similar to the modern reverberatory furnace where the flame is diverted back from the roof to strike the charge and heat it.

For manufacturing large objects like cast bronze cannons or iron forging like Delhi's Iron Pillar the furnaces were constructed at the site itself using locally available raw material and as described by Bonner et al. (1972) expert blacksmiths and workers were invited from distant places to perform the job. Bonner et al. have also described a variety of tools and techniques used in the construction of the Sun temple of Konark. One very specialised technique described by them is the use of

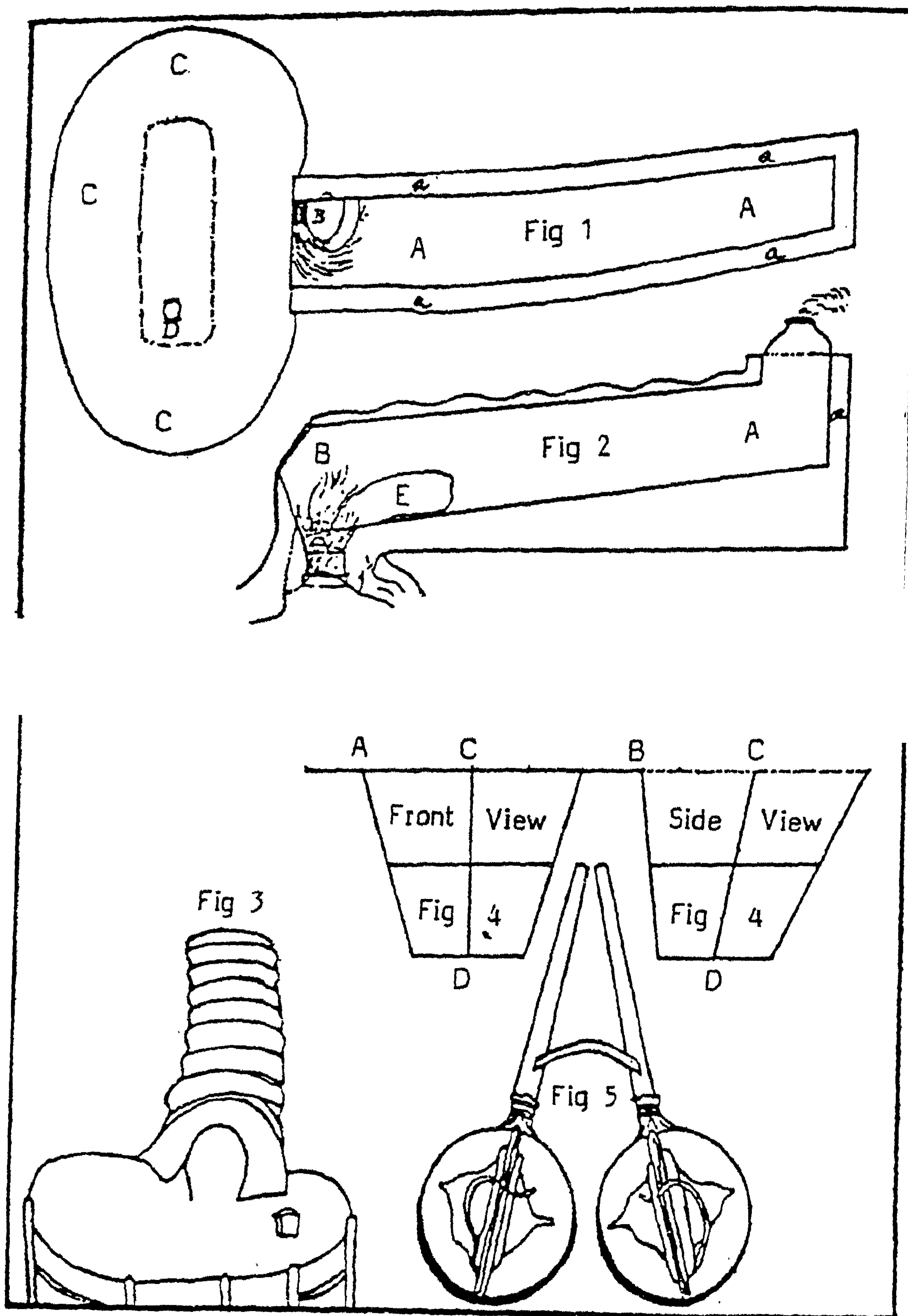


Fig. 59. Sketch of a reverberatory furnace described by Mahmud. It is very similar in construction to the present day furnace

lead bath for manufacturing the iron beams, although from their description the specific purpose of the use of molten lead mixed with Borax is not very clear. Nagarjuna (Biswas 1981) is considered to be the father of Indian Alchemical Science, and according to Bose et al. (1971) and Filliozat (1951) his work is dated to 1st century A.D. and not 10th century A.D. as estimated by Alberuni. *Rasa Ratna Samuccaya* (8-12 century A.D.) has described variety of crucibles (Musa), Yantra and furnaces for the manufacture of Ayurvedic medicines.

It also describes in total 51 kinds of metallurgical tools (*upkaranas*), 36 kinds of equipment (*yantras*), 17 types of crucibles and 9 types of furnaces for giving *Puṭas* such as *Mahāgajapuṭa, Gajapuṭa, Ardhagajapuṭa, Kukuṭapuṭa, Kapoṭapuṭa* etc.

Fig. 31 shows a sketch of Aṅgār Koṣṭhi capable of achieving temperature of the order of 1500°C. the dimension of this furnace are very similar to those of modern crucible furnace. It also mention the detailed design of the *Rásā Sala* or Alchemical laboratory.

From the description of the process of metal extraction and metal working it is very clear that the metal smelters and smiths of India had gained very advanced knowledge regarding the thermo- mechanical behaviour of Au, Ag, Cu, Pb, As, Zn, Hg and Fe and their various alloys. They had also the skill to produce a variety of objects of intricate design and gained experience in soldering, forge welding, rivetting, casting and thermo- mechanical treatment as well as metal finishing technology and they used very precisely designed tools and furnaces for these purposes.

Conclusions

Tylecote(1984) has rightly mentioned that India's 'History of Science and technology' is yet to be written and the available date is in no way complete to expose its full potential. In this context the description of the ancient metals and the technology presented in this Chapter is only the tip of the iceberg of the knowledge and skill of the ancient Indian craftsmen.

It can be said beyond doubt that the discovery of metals and the techniques of their use in day-to-day life has been of Indian origin and not borrowed from abroad as mentioned by many noted Archaeologists of the Western World.

Based on the caste system the technology of smelting and working of specific metals was being practiced by a particular group of the tribals who were maintaining the details of the knowledge in their family, from generation to generation. The technological practices were considered to be a highly guarded family secret and a religious pursuit of very high order. These stringent beliefs and rituals of the society are also responsible for the perishing of many ancient art and craft.

Some of the highlights of the ancient Indian craftsmen are :

(1) The smelters and metal smiths had gained a very high degree of knowledge regarding, furnace design, combustion of fuel, refractories and skill in operating the furnaces under a predetermined condition and at desired temperature.

(2) The Indian Black-smiths had gained very detailed knowledge about Fe-C alloys and Wootz steel and they had mastered the skill of thermo-mechanical treatment to produce excellent swords with typical watering treatment, Serian's had come to know the Indian source of the steel ingots and learnt the technology of working it to produce "Damascus swords" in their country.

(3) Indians were also first to introduce Zinc to the human civilization and also develop Cu-Zn alloys.

(4) The alloy technology of the country was very refined and alloys of controlled composition could be produced repeatedly.

(5) The skill of designing of a variety of objects of art, their molding by various methods such as the die casting molds and lost

wax process and casting of small as well as large objects was highly developed in the country much ahead of the world.

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Methods of Coin-making

B.N. MUKHERJEE

Sources of our knowledge of minting coins in ancient India consist of indications given by the relevant coins, archaeological finds (other than coins) and references in literature. The extant specimens of coins are mainly in silver, copper, gold, lead, billion, potin, bronze and brass.

On the basis of discernible minting techniques, ancient Indian coins can be broadly divided into four classes, viz, (i) archaic die-struck including the so-called 'punch-marked', (ii) cast, (iii) repousse and (iv) die-struck. In contrast to the coins of class I those of class IV may be characterised as "sophistically" die-struck.

Devices on a large number of silver and copper coins do not cover the whole or most of the flan. Here the devices are impressed by separate punches with various dies 'applied irregularly at various points on the surface'(Smith, 1906). This peculiarity led Prinsep to use the term 'punch-marked' for describing this series of coins (JASB, 4, 1835, p. 627). For manufacturing such pieces a prescribed amount of metal (and alloying materials) should have been melted in a crucible and the molten metal was left to be cooled as a lump or was cast into sheets of required thickness.

In case of a lump, it had to be beaten out into a sheet. Strips, cut out from sheets of this type, were divided into pieces of same weight and final adjustments were made by cutting small bits from one (or more than one) corner of heavier pieces. Where such trimming was not necessary the pieces cut out from the sheets could be roughly of the required size (square, squarish, rectangular, oblong, bar-shaped, round, nearly round, oval, etc.) If the sheet was very thick, the rectangular or square pieces cut out of it would look like ingots. These pieces of prescribed weight, technically known as blanks were probably slightly heated and then impressed with devices from different dies punched on them on one or both of their two sides (obverse and reverse). The deeply struck devices would look like independent incuses on a flat and fairly broad surface. If a bar-shaped blank was struck heavily with two devices at two ends, it would naturally bend in the middle resulting into a bent bar coin.

Some irregularly oblong or roundish coins give the impression of having been formed out of drops of molten metal. Here the dropped blank[1] (in contrast to cast blank or beaten-out lump blank) was perhaps stamped with a symbol or symbols while still in a semi-molten stage. A number of saucer shaped coins and numerous small coins might have been minted with the help of dropped blanks. If the quantity of dropped metal was sufficient enough to be impressed by only one die and if the die was struck very hard, the blank would have resulted in a saucer-shaped coin.

In case of the dropped metal having been very small in quantity (looking like a small molten globule), the resultant blank was very small in size, often not being spacious enough to receive the impression of even one die. However, such cup-shaped and minute coins could well have been produced out of beaten-out or cast blanks[2].

All these varieties of specie were struck with dies. So all of them can be broadly called die-struck coins. However, they lack the more sophisticated technique and appearance of regular die-struck pieces. Both sides (obverse and reverse) of most of the latter pieces appear to have been struck simultaneously with two dies (obverse and reverse dies). On the other hand, the archaic die-struck pieces bearing more than one symbol on at least one side seem to have been impressed with them by punches from different dies, all of them having not been struck simultaneously (even when impressed on one single occasion). Such pieces, which received more than one 'punch' should be strictly classed 'punch-marked'. These as well as the others bearing not more than one 'punch' on one side may be loosely classed under the category of 'archaic die-struck pieces'. There are indications that the coins displaying not more than one symbol or marked on one side were in circulation in *inter alia* the period of regular minting of 'punch-marked' pieces (Curiel and Schlumberger, 1953; Marshall, 1951; Mukherjee, 1977).

The evidence of the larger Bhir mound (Taxila) hoard indicates the circulations of the punched-marked coins in the 4th century B.C. The contents of the Chaman-i-Hazuri hoard may be considered to allude to the minting of the punch-marked pieces even in the 5th century B.C. The use of the punch-marked coins on a large scale in the Maurya period has already been suggested (Mukherjee and Lee, 1988).

In the light of these inferences we can discuss the minting of coins as indicated in the *Arthaśāstra* of Kauṭilya, generally attributed to the Maurya age (late 4th to early 2nd century B.C.) Kauṭilya referred to a list of objects used in the atelier of a counterfeiter of coins (*Kutarūpakāraka*). These included metals, alkali, crucible, charcoal, bellows, tongs, hammer, chisel, anvil and die engraved with design (bimba) (Arthaśāstra, IV, 420). Same articles were apparently used in a regular mint. It appears that lumps of metal were fired with purifying agents (including some other prescribed metal)[3]. Then prescribed quantities of 'purified' metal lumps and alloying materials were melted in crucibles and the molten mixed metal (including the hardening alloy) was cast into sheets (or mixed metal lump was hammered into sheets). The sheets or strips from the sheets were cut into pieces of required size and weight. The sheets or blanks could be blanched with alkali. Then the blanks (cold or slightly heated) were placed one after another on the anvil and stamped by the die (bearing the design in negative) with the help of a hammer. If

more than one design was to be impressed on the blank in one single operation, relevant number of dies (each carrying one design in negative) were used one after another.

Kauṭilya recommended minting of silver and copper coins. According to him, the *Lakṣaṇādhyakṣa* (i.e. mint-master) should manufacture 'silver' coins with one-fourth part copper and a māṣa of supporting material (*vīja*) (i.e. hardening alloy) consisting of iron, tin, lead or antimony[4].

In a silver coin of *paṇa* denomination, weighing 16 *māṣas*[5] only 11 *māṣas* were of pure silver. In case of a copper coin the sustaining material (*ājīva*) (i.e. hardening alloy) was one-fourth of its total weight[6].

The method of coining indicated by Kauṭilya might well be applicable to the manufacturing of many of the above noted types of archaic coins including 'punch-marked' pieces. Unfortunately archaeological remains of any mint used for producing such coins have not yet come to light. Nevertheless, we have data to indicate atleast the major stages in the production of these coins. The manufacturing method does not appear to have been very sophisticated. In fact, the practice of stamping semi-molten lump or drop of metal or striking the blank successively (or at intervals) from different dies (as on punch-marked pieces) was laborious as well as detrimental to the quality of production. However, devices or symbols stamped carefully with well engraved dies could have produced clear and artistic reproductions on blanks.

II

A great number of coins carry devices, which are not as sharply cut or clear as those on a great number of archaic coins including the 'punch-marked' series. These devices seem to have been impressed on coins not by hard striking, but by casting metal in moulds bearing the required impression in negative. The process of manufacturing these coins involves preparation of mould(s), melting of metal and casting of the latter in the mould(s). The negative of the intended coin-type could have been engraved or etched on a blank mould made of heat-resisting plastic clay or on a mould in cast metal. It was perhaps technically also possible to have the mêtal mould with the intended impression by casting the required amount of molten metal in a clay mould bearing the positive of the impression in relief. Similarly, according to an alternative and possibly more convenient method of preparing a clay mould for producing coins, the intended coin-device could have been carved in relief on a lump of clay or on a piece of metal. It was not difficult to rectify the positive impression, if it was found necessary. The latter, made either in clay or metal, served as a model. By pressing this positive impression on a lump of heat-resisting plastic clay, specially prepared according to the shape (round, rectangular, square, etc) and size of the intended coin, a mould was made, consisting of the intagliated negative impression. The mould with raised rim around the coin-socket was then baked.

Molten metal, of pre-determined quality was now poured into the mould. Gradually hardened, it would receive the positive impression of the type found in

negative on the mould. Some copper coins bearing device only on one side may have been minted following this process.

If a coin was destined to carry devices on both faces, a second mould had to be prepared and an opening made through the rim of each of the moulds. The openings as well as the moulds were then jointed face to face. Molten metal could now be poured through the channel and into the cavity thus formed.

Some cast coins found still joined together by a bar of metal indicate that these were cast in pairs. Each pair of moulds (bearing obverse and reverse devices), facing each other, were jointed with another pair of moulds by a channel. Molten metal poured probably through a hole in the channel, could flow into each socket. But in the process some portion of the metal could have sometimes dried up in the channel resulting in a bar joining both the coins. Ordinarily the bar should have been broken and detached from coins. But sometimes this was (mistakenly) left attached to the pair of coins.

Some of the Yaudheya coin moulds, found at Sunet, consist of pairs of discs bound together back to back (i.e. by their blank faces) with the help of mortar. This evidence suggests that sometimes pairs of discs, each forming a set of moulds for obverse and reverse devices, were placed one above the other so as to make a cylindrical pile.

The engraved faces of each pair of discs faced each other, while the blank side of each of them was attached to the outer side of the immediately upper or lower pair (as the case might be). The opening on the rim of each pair (as indicated in the last but one paragraph) was usable for channelling molten metal into the inner side. Available data indicate that the series of discs was then plastered over on the outer side, leaving only the channels leading to the sockets uncovered. Molten metal could now be poured into different moulds separately, or, which was more likely, it could be made to flow down through a vertical hollow column communicating with the channels leading to the coin sockets of the moulds placed vertically. The practicability of the latter method is indicated by the 'U'- or 'V'-shaped cut leading right into the socket of some Sanchi and Sunet moulds. The deep cutting through the side of each of these moulds seems to have been designed to allow metal run directly into the socket from some central channel (like the above mentioned vertical hollow column).

The method of letting the molten metal flow down the hollow column was less time-consuming than that of pouring through the opening in each pair of discs. In the former case several coins could be made in one single operation. However, it also had greater risk of loosing part of the metal before reaching the socket, Commenting on the above noted moulds from Sunet, B. Sahni has observed that two or more cylindrical piles of moulds have been joined together "round a vertical axis so as to bring all the individual channels into communication with the single axial canal fed through a crater at the top" (Sahni, 1945, p.36). Similar Roman coin moulds have been discovered at Lingwell Gate in England (Sahni, 1945, pp.36 and 52; Pl. VII, Figs.143-45). It is significant to note that the Sunet moulds of the later Yaudheya coins are to be dated long after the inception of Indo- Roman trade.

More interesting are the discoveries of several coin sockets in single coin moulds. The shape of such moulds is either rectangular (as that of an Atranji Khera

or Taxila piece) or circular (like that of several Taxila finds) in shape (Sahni, 1945, pl. VI, no.126, pl.V, no.123, nos.119-122). The rectangular coin mould from Atranji Khera displays the negative impressions of Huviṣka's coin devices in sockets arranged in rows. Only the sockets of the row nearest to the opening on the rim or the mould received molten metal through channels connecting them with opening. Each of the sockets in succeeding rows received metal through the channels connecting it with the nearest socket of the earlier row and also of the same row. Pairs of such moulds were often used to be fixed face to face with the help of tenons and were probably plastered over. Several Taxila moulds, however, do not betray traces of tenon or mortise. Here "the funnel-like inlet on one side of a mould narrows into a final canal which feeds the nearest coin socket and it is from this socket that all others have to be fed by narrow connecting channels" (Sahni, 1945, pp. 41 and 48).

A similar arrangement was noticed by J. Dattari in some Roman moulds discovered in Egypt (Sahni, 1945, pp, 42 and 54). Several copper coins yeilded by a hoard at Masubazar (32 miles south of Purulia in West Bengal), which are joined with one another by metal bars, might have been produced through an analogous method.

A complete set of three discs, found at Mathura, have the top and bottom ones blank on their exposed sides. Their inner faces bear coin sockets, while the central discs have coin-impressions on both faces. Traces of luting on the outer side indicate that these were plastered over. A part of the edge of the middle disc was cut away into a 'V'-shaped notch, with a straight channel on each face leading from the notch to a point just beyond the centre. From this main channel four short branch channels came off at straight angles, two from either side of it. The ends of these four channels and that of the main channel itself communicated with the five coin sockets.

To complete the opening at the edge of the triple mould, the two outer discs were excavated on their inner sides into shallow depressions which were either fitted opposite each other (on either side of the notch in the middle disc), or lay obliquely on two sides of the middle disc. Molten metal could be poured through the channels made of the above noted 'V' shaped notches (on two sides of the middle discs) and depressions (on the inner sides of the outer discs).

The most elaborate process of coin-casting has been revealed by the fragments of early Yaudheya coin moulds found at Khokrakot, near Rohtak. Each disc seems to have a hole in the centre, from which radiating channels run into eight coin sockets arranged in a circle.

B. Sahni thinks that at first a clay disc was prepared around a peg on the middle of a base plate enclosed by a hollow cylinder. Then an eight-rayed metal with a hollow centre was slipped down the peg and pressed on the clay. At the end of each of the radiating channel, thus excavated, "a coin model" was pressed to create a coin socket bearing the negative impression of the obverse or reverse concerned.

Two discs, prepared in this way and coupled face to face, made one pair. Two such discs, one carrying the obverse and the other reverse impressions, were coupled face to face and fixed to each other with the help of tenons. Several pairs of discs, placed one above the other and marked with grooves cutting the outer face

of the rims, formed one set. A number of such sets, dried up in sun, were placed one above the other. These were then plastered over with a paste of clay mixed with unhusked grain and then baked in a furnace. However, the central hole of the top disc and so of all discs were left open.

These holes formed a hollow shaft. Molten metal poured down through it, with the help of a funnel-like opening at the top, would run by means of the radiating canals of each pair of discs into the cavities of coin sockets. B. Sahni is of the opinion that casting was done when the pile of moulds was still hot. The pile was probably enclosed in a furnace into which wind was passed with the help of a bellow, and the molten metal was probably poured in the manner described here. When the pile cooled down after the operation, it was broken up and coins were then taken out and cleared.

The Rohtak moulds may be compared with ancient Chinese system of casting coins in a circle (T de Lacouperie, 1892, p. xxv), or with a stone mould for casting ten Pao luh kwa coins "arranged like a tree whose stem and branches are the rivulets for the metal and fruits or leaves the coins" (T de Lacouperie, 1892, p. xxviii; Macdonald, 1916, p.61; Sahni, 1945, p.55).

A great advantage of the Rohtak system of casting coin was its capability of producing a very large number of coins in one single operation. However, an equally great disadvantage was that the moulds were broken and lost in that process. This drawback might not have been always faced in casting coins in moulds having one socket. At least we have evidence of producing coins in modern times from such ancient Roman moulds (Sahni,1945, p.52). As part of the metal was likely to be lost in channels and before reaching sockets, it was difficult to control weight of each and every cast coin. This fact explains the divergence in weight of cast coins of apparently one and the same denomination. A part of the metal hardened in the channel leading to a coin socket in a mould which was sometimes left unseparated from the metal hardened in the socket. This distorted the shape of the coin produced from that socket.

Again faulty casting could allow formation of air bubbles in the metal, resulting in the fragility of the coins concerned. Moreover, mould-impressions were not always properly transferred (with all their details and sharpness) to coins since such a transfer was not mechanically or manually controlled.[7]

III

The apprehension of loosing matrices or of failure to ensure sharpness in devices on coins did not apparently plague the producers of a few classes of coins of thin fabric and light weight (Altekar and Mukhejee, 1982, p. 1387). These pieces bear devices on one side only, the other side carrying only their negative impressions. Apparently the thin flan of such a coin was placed on a piece of stone or metal displaying the positive impression of the device concerned either in high relief or in a sunken state. Then the thin blank was carefully hammered to receive on one of its sides the positive impression of the device either in relief or as incised

(depending on the manner in which it appeared on the matrix). Consequently the other side of the thin flan got intagliated or raised traces of the device in negative. This process of transferring impression from a matrix to a piece of metal, popularly know as the repoussé technique, allows production of numerous coins from matrix and ensures good impression of the matrix-device on coins. But the repoussé technique not only involves a laborious and time consuming process, but also does not allow impressions of two distinct devices on two sides (obverse and reverse).

The insignificant number of known pieces, minted according to this technique, indicates that the repousse method of production was the least popular among moneyers. Probably its defects outweighed its merits [8].

IV

These difficulties faced in producing casts or repoussé coins could have been obviated by following another technique of minting. We are referring to the system of producing coins with the help of well prepared blanks and dies (each of which, meant to be impressed, with the exclusion of others, on obverse or reverse, bears a cohesive picture of devices related to one another or such devices and legends or only a meaningful legend or a part of it). This system was, at least in the early centuries of its use, a sophisticated development on the above noted archaic die-striking (including 'punch-marking ') methods.

Among the most well produced die-struck series of specie of Ancient India we can include the coins (or at least many pieces) issued by the Indo-Greeks, Schtho-Parthians, Kuṣāṇas and Imperial Guptas. The appearance of two distinct devices or rather two distinct sets of cohesive devices of their coins and traces of double striking on blurred faces of some of these pieces suggest that the coins of these rulers were struck from two separate dies, used probably simultaneously. The method of die- struck coins of the Gupta and Pre-Gupta periods consisted mainly of gold, or silver, or copper or lead or billon (an alloy of silver with copper or tin), or potin (a compound of copper, lead, zinc and tin)[9].

The exact process of extraction (or segregation) of crude metal from native metal deposits and also the exact process of purification or refining of crude metal varied from metal to metal, as suggested by mediaeval and modern experience. However, a few early and mediaeval treatises perhaps indicate that firing of the metal was an essential part of each method (*Dravyaparikṣā*, 17ff; *Āin-i-Akbarī*, 6,3-9; 10-14; Viccaji; Ray, 1956, p.209 vide Parrington, 1961 pp. 716ff; *Arthaśāstra* IV, 4, 20; 11,13, 9 and 49).

'Purified' remains of gold, copper, silver, etc., could have been melted and cast into ingots. "Mixed" metal like billon or potin could have been prepared by mixing prescribed quantities of molten metals and then casting the materials into ingots. These ingots supplied the basic materials for preparing blanks.

It appears that the required amount of basic material was first melted down. The molten metal could have been mixed with prescribed quantities of alloying materials (whenever necessary), as in the case of preparing gold or silver coins.

Then the required amounts of molten metal were probably poured into circular shaped moulds of regulated sizes.[10] The blanks produced for the moulds could be heated and worked upon by hammering, etc., for achieving the required thickness and for destroying the brittle cast structure of their grains and thereby making them conducive to receiving the blow at the time of striking. Alternatively, the molten metal (mixed with alloying material) could have been cast into sheets or plates, which could be heated and worked upon and finally cut into round pieces of the size of the coined money.

After preparation of blanks their weight might have been checked and adjusted according to the specified standard. We do not know whether, as in several manually operated mints of medieval and early modern times, the blanks were blanched by boiling them in a solution (like that of tamarind and salt) in order to clean and perhaps also to soften them.

Preparation of dies was another important stage in production of coins. Impressions in relief on most of the well produced die- struck pieces suggest that devices on the relevant dies were hollowed out. We can guess two, if not more, possible ways for preparing these "intaglio" dies.

Negative impressions of the obverse and reverse types (and inscriptions) could have been engraved, perhaps following an original design, on two separate dies of soft steel or bronze, prepared by cutting into slices a bar of steel or bronze, cast in mould and then annealed (i.e. softened by heating the bar to a temperature somewhat below the melting point and then allowing it to cool slowly)[11]. The engraving might have been done by a sculptor with the help of such instruments as a graver's wheel, drills of different shapes and sizes, a burin, a hammer and perhaps a compass.

We can consider an alternative and perhaps a more practical or an easier way of making dies. The sculptor could have engraved in positive the obverse or reverse design on a lump of specially prepared plastic clay containing aluminium silicate and so possessing high heat-resisting capacity and high softening point (PCE).

The lump of clay displaying the design would have to be fired properly. Then the terra-cotta design or model could be covered by molten ingredients of steel or bronze for transferring the design in negative on the gradually hardened material[12].

Increased hardness could be achieved in case of a metal die, prepared following the first or second process, by heating it to a temperature somewhat below the melting point and cooling it by water quenching.

The obverse and reverse dies were now fit to be used in a mint. One of them was fixed on or embedded in an anvil. The other die was attached to (or engraved on ?) a (square or an oblong shaped?) punch.

Each metal blank was heated or was slightly softened by annealing (to make its hard material ready to receive the required impressions) or was left cold. The blank was then set on the die fixed on the anvil and the die-end punch was placed on it (i.e. the blank).

The fact that the reverse type on numerous die-struck coins is found double-struck and/or partly out of flan does not at least indicate a regular use of any mechanical instrument (like a hinge connecting the two dies)[13] to keep the upper

die in proper place during the time of minting. Nevertheless, a regular alignment of the obverse and reverse impressions on a great number of coins suggests that care was at least sometimes taken before striking to put the upper and lower devices parallel to each other.

The actual striking seems to have been done with the help of a hammer. After placing the die-end of the punch on the cold, or annealed or incandescent blank already set between the anvil-die and the punch-die the other end of the punch was struck with a hammer. As a result both sides of the blank received the required impressions and it was transformed into a coin. A recent experiment in Greek minting technique reveals that two blows of the hammer were sufficient to give full impression of both the dies on the flan (*NC*, 1963, p.226).

Several coins, scrutinised under microscope, show homogeneity or near-homogeneity in size of the grains of their metal.[14] This indicates that even if the coin was cold worked, the cast metal of the blank was heated and worked out (as indicated above). Or we may presume that a cold worked coin was heated to a high temperature to remove the strain sustained by its metal at the time of striking. At the time of heat treatment a good amount of recrystallisation could have taken place making the metal quite homogenized from the point of view of size of its grains. The same effect could have been achieved by striking the blank at a high temperature. But the hot-working could have affected the die-life.

An examination of a large number of coins apparently intended to be round reveals that only a few of them are exactly circular in shape. It appears that the very method of production followed in ancient Indian mints made it impossible for the true circle to be obtained, since there was nothing to stop the flan from spreading irregularly under the blow of the hammer.[15]

Unutilised space around the full impression of a reverse device can be noticed on a number of coins. This indicates that in these case the punch-die or the upper die was smaller than the blank set on and covering the face of the anvil-dies.

The use of smaller upper die may have originated from the desire for allowing the blank to have enough space to receive the full impression of the reverse device even if there was some oscillation of the punch-die during the time of manually operated production. We should also note that the available evidence in other fields of numismatic research shows that an upper die (trussel die) was less durable than the lower die (pile die). So in a given period a mint might require more upper dies than lower dies. Hence the smaller size of the punch-die could have lowered the cost of production in a given period which would have been otherwise grater then the amount required for manufacturing the anvil-dies. As a result of hard striking by the smaller upper die on the blank its outer marginal part outside the area stamped with the relevant device became a little raised. Such concave reverse may be noticed on some coins, which have convex obverse (Mukherjee, 1967, Pl VI A, No. 9; Pl. VIII A; No.21; JNSI, 1956, Vol.XVIII; Pl 1, No.2f).

Defects of various types, as noted above, are, however, not noticeable on a large number of coins of the pre-Gupta and Gupta ages including numerous Indo-Greek, Kusana and Gupta pieces. Many of these can be classed as objects of art. (Mukherjee 1978, pp.16ff; 1982, pp.20ff; 1983, Vol. XVII pp.22 ff). Production of such quality

die-struck coins depended on the artistry of the obverse and reverse devices, excellence of the relevant die(s), purity and/or suitability of the required metal, efficiency in technique of minting and will and resources of the minting authorities (Mukherjee, 1982, pp.10 and 64).

The majority or even all of these conditions remained unfulfilled by the strikers of the greater number of series of specie in the post-Gupta age, when a large number of ruling families did not at all strike coins (Mukherjee, 1982, p.66, n.2) We even do not know of coins of all members of all the ruling families of this age, who are credited to have their own coinage.[16] There are reasons to believe that coins were used to be minted by rulers of at least certain dynasties only when there was demand for them in market and then also new pieces were struck often with old familiar types (Mukherjee, 1982, pp. 66-67, n.3) and sometimes even with the names of dead rulers (whose coins had already become popular with the people). Private moneyers were also allowed to mint coins. They were understandably not at all keen to maintain the quality of coins and purity of metal. As a result, coins bearing the name of a ruler might have continued even after his death, to be imitated in gradually debased metal and technique (Mukherjee, 1982, pp. 49ff).

This situation explains the hopelessly debased materials used in minting several series of die-struck specie in post-Gupta India (Mukherjee, 1982,pp. 39,41, 43, 49 etc). On many coins the figures are ill-executed and even grotesque, obviously due (partly or fully) to deficiency (a) in the merit of the designer, and/or die engraver (or designer-cum-die-engraver), and (b) in the metal of the die, and also (c) in the technique of minting.

, On a fairly large number of coins an emphasis on delineating only the outlines of the figures in high relief is noticeable. This technique of execution was probably necessitated due to use of poor and alloyed metal and of dies deeply sunk in the relevant places only (Mukherjee, 1982, pp.43 and 53).

Economic and political factors led to deterioration in the system of coinage, affecting seriously its typological, metrological, and technological aspects. The situation was quite chaotic when the power of Islam became firmly established as the most dominant political authority in the subcontinent in the 13th century A.D. However the conditions of minting became, to some extent, improved in the next few centuries, particularly in the age of the early Great Mughals.[17]

Notes

1 *Valdettaro (JNSI,35, Pl.1. no.13, 1973) and, following him, A.N. Lahiri, calls the pieces in question as "droplet" coins (JNSI, 1976, vol.XXXVIII, p.4). The word "droplet" means "a little drop". But a blank of this type of coins might have been produced by a large drop or several small drops of metal. So it is*

wise to categorise the blank simply as made of "dropped" metal. Some dumpy silver coins found in the Bhabua area of the Sahabad district might have their blanks prepared in the same way (JNSI, 1973, Pl.I, no.13).

2 *Examination of several pieces of these types gives this impression.*

3. *The Arthaśāstra refers to the purification of impure silver by adding lead to the extent of one-fourth of the weight of the silver (II; 10, 13) and apparently by heating the total mass of metal. In another place the same text recommends that impure silver should be heated four times in a crucible of bone (i.e. made of a mixture of clay and bone dust?), four times with equal amount of lead (in a pot of clay), four times in a dry crucible, three times in a pot-sherd and twice in cowdung and then it should be made bright with Indus-earth (II, 13, 49). According to Pliny, silver ore "cannot be smelted except when combined with lead or with the vein of lead, called galena. The lead ore, is usually found running near veins of silver ore. When submitted to the process of firing, part of the ore precipitates as lead while the silver floats on the surface, like oil in water" (NAH, XXXIII, 31, 95). For the purification of crude gold the Arthaśāstra indicates the use of lead and heating of the mass by cow-dung fire (II, 13, 9). The sufficiency in the degree of purification was to be attested to by an equation of the quality of the colour of two lines drawn on a touchstone, one by a piece of pure gold and the other by a part of the material (varṇikā) already heated for attaining fineness (II, 13, 17).*

4 *Arthaśāstra, II, 12, 24. For Kauṭilya's prescription for purification of different types of metal, see ibid,11,13*

5 *Arthaśāstra, II, 19 refers to a dhāraṇa of silver as weighing 16 māṣas. Dhāraṇa as the name of a silver coin was of the denomination of silver kārṣāpaṇa, paṇa, or purāṇa.*

6 *Arthaśāstra, II, 12, 24, according to Kauṭilya, a rūpadarśaka or coin-examiner should test the purity of hiraṇya (ibid, II,5). The term hiraṇya generally means "gold" or "gold coin" it may, however, also refer to coin in general.*

7 *The practice of producing cast coins in official mints declined after c.3rd-4th century A.D. In the Gupta and post-Gupta ages the casting method was perhaps increasingly adopted by counterfeiters for imitating coins struck officially from dies. It is interesting to note that the moulds found at Kadal in the Deccan bear legends in the Nāgarī script datable to the period from the 11th to 15th century (Sahni, 1945)*

8 *Gupta and Jha (Ed.), 1987, p.129.*

9 *A small number of coins, including a piece attributed to Candragupta II, are considered to be made of brass (Mukherjee, 1982, p. 32, n.41)*

10 *Some clay-slabs or cakes were found at Bhambor and Brahmanabad in Sind. These "are about half to three- quarters of an inch thick, upon one side of which are impressed rows of little cup-like hollows, forming a regular honey-comb pattern, while the lower sides have been subjected to great heat and are vitrified". A few of these were found during excavations at Bahmanabad along with some pellets, which fitted the hollows, and some copper coins, produced apparently by striking such pellets with dies.*

According to a hypothesis, these were "first heated upon a furnace to prevent sudden chilling of copper" poured into the cavities. After the molten metal became frozen in the hollows, they took the size and weight of intended coins. These slabs were used for minting coins of Arabic rulers (ANRASI,1903-4 p. 137; pl. XLVIII, no. b).

11 *Del Monte, 1961, p. 21. It was perhaps also possible to engrave the negative impression of a design on a block of stone and then to use it as a die. (In this connection see also NC, 1922, p. 2).*

12 *It was also possible to cut a positive design in high relief on the lower end of a bar or punch and then to punch it on soft metal to produce a intagliated die with the negative impression. This method, known as hubbing, allowed die-cutters to have identical dies from one master punch (NC, 1922, pp. 18-22; 1963, p.221). The positive impression could also be impressed, while the bar or punch carrying it was hot, on a piece of hard wood. The latter could then possibly serve the purpose of a die (NC., 1922, p.2). It is difficult to ascertain whether the system of hubbing was known to ancient Indian mint-masters.*

13 *That the Roman mints used hinge "is proved by the discovery in Gaul, of an obverse and a reverse die of Constans I, still so connected". Alternatively, the upper die might be so constructed as to fit on to the lower one like the lid of a box, as is the case with a pair of dies of Faustina Junior, now in the Lyons Museum (Macdonald, 1916., p.66; COROL, 1906, pp. 178f).*

14 *The coins so examined belong to the Indian Museum, Calcutta. These were examined under microscope at the Conservation Section of the Museum.*

15 *There is no evidence of the use of any type of collar around the dies to check the blanks from spreading out (see also. Linecar, 1962, p.25).*

16 *"Bull" and "Horseman" devices were used not only by different members of the Shahi Dynasty, but also by rulers of other families. The "seated goddess" type of Gāṅgeyadeva influenced the coin type of several other groups of rulers.*

17 *For a discussion on minting in medieval India, see Mukherjee and Lee, pp.23p.f; pp.24-25 .*

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Ceramic Technology

M.K. DHAVALIKAR

Introduction

The invention of pottery is a most important landmark in man's march from barbarism to civilization. Although the earliest occurrence of pottery is generally attributed to the Neolithic period when man first began to enjoy the luxury of settled life, recent evidence from West Asia shows that pottery came to be made by man in the later stage of the Neolithic, and that there is an aceramic stage preceding the use of pottery. In the primary Neolithic, vessels of stone and wood were used as containers as is testified by the evidence from West Asia. On the basis of radio-carbon determinations the beginnings of pottery manufacture (Melaart, p. 62) can now be assigned, with reasonable amount of certitude, to about 7000 B.C. It may also be stated that still earlier occurrence of pottery is now reported from Japan where the peasants of the Jomon culture used pottery vessels some ten thousand years ago.

Scholars have tried to explain the circumstances leading to the making of pottery. The baskets used for storage in the pre- ceramic period were lined with clay with a view to preventing the grain from falling out through the holes in the woven pattern. Such baskets have been reported from Beidha (Israel); they are coated with gypsum plaster (Melaart, p.62). It is very likely that one such basket may have accidentally fallen into fire, burning the reed work and leaving the fired clay coating which got hardened in the process.

This is a plausible explanation which has generally received acceptance. Probably because of this, the earlier vessels bear basket impressions. Once this was achieved, the potters art made strides and in a very short period of time we find that potters in West Asia began to fashion exquisite forms which were adorned with painted patterns as well. With the introduction of agriculture and the attendant settled life, the technique spread in adjoining areas too. In the Indian subcontinent also the earliest occurrence of pottery can be assigned to about 5000 B.C., as is clear from the recent excavations by the French Archaeological Mission at Mehergarh which is located on the Bolan Pass near Quetta (Jarriage and

Lachevallier, pp. 47 to 80). Here, the earlier pottery was made by hand and shortly the potter's wheel was introduced around 4000 B.C., enabling the potter to produce pottery on mass scale.

The term pottery generally denotes all objects made of clay, first shaped, then dried and finally made hard and permanent by the action of heat. Hence clay is the basic ingredient of all pottery. The raw material required for pottery is abundant all over the world. It is a decomposed and disintegrated product of felspathic and granitic rocks which forms three-fourths of the earth's surface. In India, we have some of the finest clays in the Indo-Gangetic plans. Hence, the pottery of north India has always been superior in fabric to that of the south. Pottery is abundant at ancient sites in India but its study in India was not given the attention it deserves before World War II.

It was Sir Mortimer Wheeler, who introduced the latest techniques of archaeological excavation in India during 1944-48, and emphasized the importance of the study of pottery in Indian archaeology. As a result, ancient ceramic industries of India have been studied during the last four and half decades. However, it should be stated that scientific studies of Indian pottery are still inadequate and we do not as yet know the technology of several ceramic wares.

Black-and-Red Ware

The black-and-red ware is one of the most important ceramic industries of ancient India (Srivastava, pp. 372-417). The vessels of this ware are usually black inside and on the rim on the exterior, while the remaining part of the external surface is red. This result in the colouration of the ceramic has generally been ascribed to the peculiar firing technique. Till recently the black-and-red pottery was taken to be characteristic of the megalithic burials of South India, but recent discoveries in different parts of the country indicate that the antiquity of the pottery goes back to the latter half of the third millenium B.C., as it has been found at Harappan sites in Saurashtra. Moreover, it is also a distinguishing feature of the Ahar culture of the Copper/Bronze Age, datable to the first half of the second millenium B.C. In Central India and the Deccan the black-and-red pottery has been found to be associated with the chalcolithic painted black-on-red pottery. (*Fig.1*) The ceramic also occurs in the early historical levels almost all over the country, and above all, it is a distinguishing feature of the megalithic culture of South India belonging to the latter half of the first millenium B.C. All this goes to show that the pottery was in use in India from the middle of the third millenium B.C. till about the beginning centuries of the Christian era. Its distribution is equally widespread; it is found almost all over the country from Gujarat in the west to Bengal in the east and from Punjab in the north to Kerala in the south. It will thus be clear that the BR ware has a wide distribution in the country both in terms of time and space. It may, however, be stated that it does not occur anywhere in the country after the opening centuries of the Christian era. The ware thus has a long history of 2500 years and it can be called the most important ceramic of ancient India.

The BR pottery has been reported from outside India as well. It occurs in the Neolithic Egypt at such classic sites as Al Tasa, Al Badari and Naqda where it was

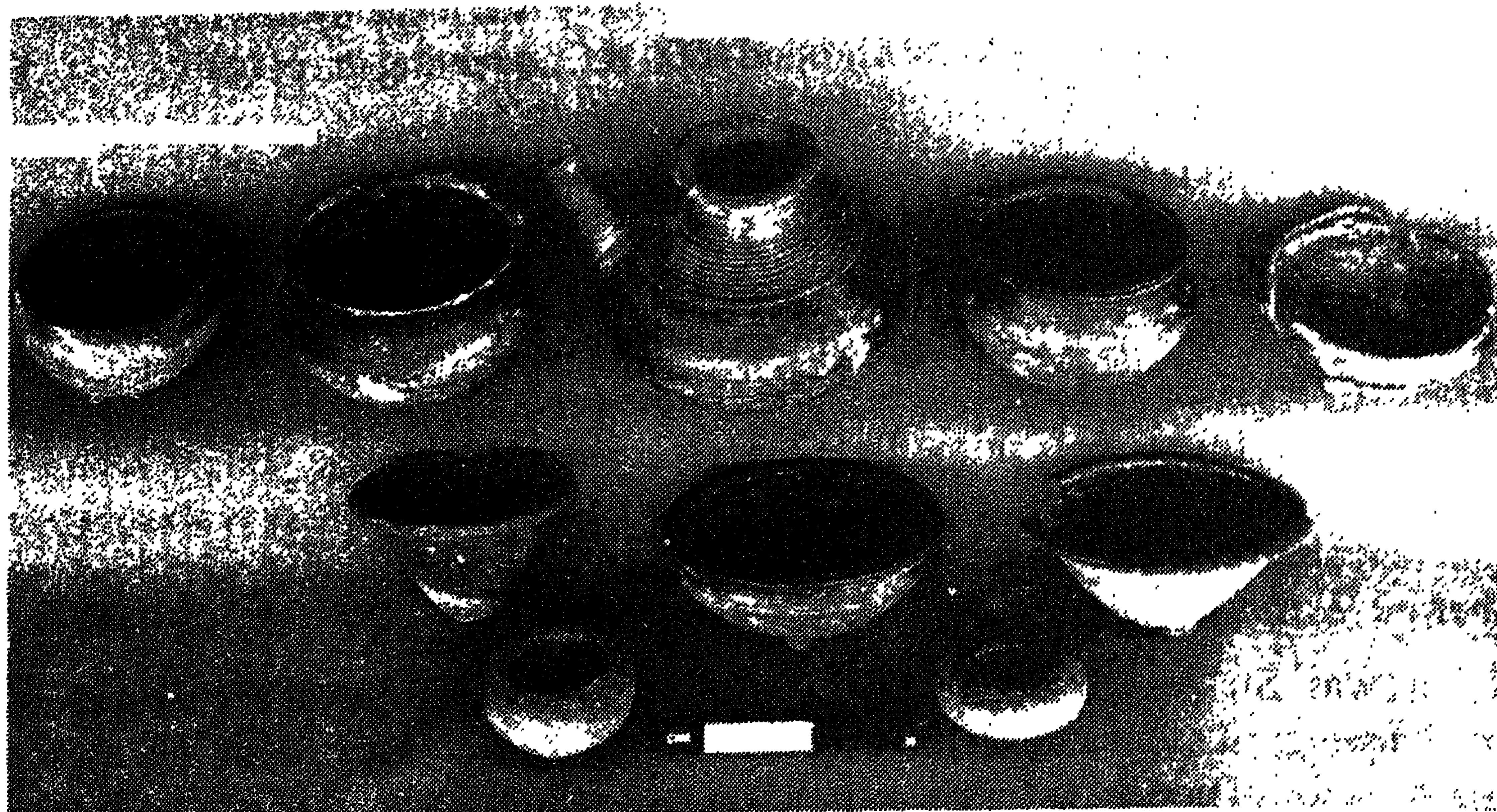


Fig.1 Chalcolithic Black and Red Ware (all except the one in the centre, top row)

formerly dated to the fourth or the fifth millenium B.C. But the new radio-carbon determinations have stretched back the beginning of settled life in West Asia to a much earlier period in the 8th millenium B.C. and consequently the date of the BR ware in Egypt may also go back to an earlier period. The pottery from these Egyptain sites has been referred to as the Black-topped ware (Honey, p. 16, *Fig.1*). It also occurs in the Neolithic Greece.

The most important problem is the technique of manufacture of the BR ware. So far it was presumed that the peculiar colour was the result of firing the pots in an inverted position in the kiln. By this process the portion of the pot, which was oxidised, turned red whereas the remaining part being fired under reducing conditions, turned black. This was the contention of Flinders Petrie and also of Gordon Childe (1937, pp. 43-44).

This was, however, contested by Lucas who, on the basis of his own experiments, is of the opinion that the colour effect of the ceramic cannot be obtained merely by inverted firing (Lucas, pp 434-36). It is in fact due to the covering of that portion of the pot, which is to be done according to Lucas in two ways - viz. a) by the simultaneous production of the red of the body (apart from any wash of red colour) and the black of this interior and the rim or b) by producing ware wholly red first and then by a secondary operation blackening the interior and the rim.

The first method was adopted by A.L. Mercer, a pottery manufacturer in USA., who, in one continuous operation made excellent imitations of the red-bodied black-topped ware, which are now in the Pitt-Rivers Museum at Oxford (Gordon Childe, 1937, pp. 43-44). In this case the desired result was obtained by keeping the pot upside down with its rim being buried in sawdust to the depth of an inch. In other words this was merely the inverted firing technique.

Lucas (pp. 434-36) also thought that some process similar to that practised by Mercer may have been in use in ancient times. But at the same time he is rather

doubtful, for he is unable to conjecture how it could have been done. He is, therefore, of the opinion that possibly the method employed consisted of two distinct operations (as in the making of modern black pottery in Egypt), the first being the making of a red pot and the second being the subjecting of the rim and the interior of the pot to the action of dense smoke in order to blacken them.

This second operation is analogous to that practised in Sudan and elsewhere at present, but instead of the whole pot being covered with chaff and other material which produce a pot entirely black on the rim only would have been covered as only this and the interior had to be blackened. G.G. Majumdar (pp. 90- 93) is also of the opinion that the BR pottery can be made only by the double firing process. Lucas (pp. 434-36) actually manufactured a few pots by employing this technique. The pots coated with a thin wash of red ochre were baked in a small electric muffle furnace. And when red hot, placed mouth downwards on a layer of sawdust in which the rim was buried. The result was a red pot with a black rim and generally, though not always, a black interior, but the red body was almost always badly smoke stained. In this process, however, the thin red wash which was applied to the pot, could be discerned even in that part of the pot which was black by merely scraping the surface and the same could also be noticed in the section.

We thus have two different processes of making the BR pottery. However, Majumdar (pp. 90-93) is of the opinion that the Indian BR ware was the result of the double firing process. It may also be stated that according to Paramasivan (pp. 231-52) the megalithic BR pottery of India was baked at 600° 700°F.He further observes that the black-and-red colouring of the megalithic pottery from Maski (Dist. Raichur, Karnataka) is only due to the presence of iron in the clay. According to him, "If the baking is done in a reducing atmosphere, the pottery becomes black. An oxidising atmosphere gives red ware".

He describes three ways in which the reducing atmosphere can be created, but does not specify the way in which the Maski megalithic BR pottery was made.

Thus there still ranges a controversy about the technology of the Black-and-red-ware. Scholars have tried to attribute the authorship of the pottery to Dravidians (Soundara Rajan, p. 74) or Aryans (Sinha, p. 11) but what seems to be the case is that this peculiar technique either originated or was introduced in Gujarat first and then diffused, in course of time to different areas. It seems to have been perfected by the megalith-builders of South India.

Harappan Pottery

The Harappan pottery is one of the most distinctive ceramics of ancient India. The Indus or the Harappan civilisation, which has been described as "the vastest political experiment before the Roman empire," was spread over the present states of Punjab, Rajasthan, Gujarat, Harayana, western Uttar Pradesh and the whole of Pakistan. Considering the distribution of the culture, it is not reasonable to expect uniformity in ceramic over such extensive area. Sir Mortimer Wheeler (1974, p. 74) rightly observes : "There is no doubt that the so called uniformity of the Harappan culture in depth has been exaggerated and is due as much to archaic methods of research as to say inherent conservation in the ancient craftsman." But

there are nevertheless certain distinguishing characteristics of the pottery which are common in all these regions. The typical Harappan pottery, both plain and painted, is made of extremely fine well levigated clay, the degraissants used were mica, sand and lime. It was uniformly fired at a high temperature and the fully oxidised cores indicate that the pottery was well baked.

It was turned on a fast wheel as the regular striation marks suggest. It is a sturdy ceramic, producing a metallic ring when struck and is uniformly thick in fabric though thin walled vessels also occur.

There are certain forms of the Harappan pottery which can be taken as fossil shapes (*Fig.2*). Among these are the gobblets sometimes stamped with inscriptions, dish-on-stand, 'S' shaped vases, beakers, perforated cylindrical jars, storage jars with heavily beaded rims and so on. Of these the goblet, the beaker and the perforated jar are usually plain whereas the others are mostly treated with a thick bright red slip over which are found painted designs in black pigment. The design repertoire is quite rich consisting as it does of both naturalistic and geometric motifs. The most distinguishing are the intersecting circles, the overlapping scales, the pipal leaf etc. Bull, peacock and fish are also present. Besides these, narrative scenes are also sometimes met with. Bichrome and polychrome pottery too occurs at some of the Harappan sites, but is extremely rare (vide Starr & Manchanda).

It has been suggested that the fine Indus pottery was probably made on a fast wheel. In this connection it may be stated that there are two types of potters wheel viz., the hand wheel and the foot wheel. The latter is operated by the potter with his foot and is much faster than the former. Ernest Mackey is of the opinion that the Indus pottery was turned on the foot wheel.

It is interesting that the foot wheel is not presently used in India today except in Punjab, Sind and Baluchistan and it is very likely that the same was in use in that area since Harappan times. Presently the foot wheel is in use in many countries of West Asia such as Iran, Israel, Iraq, Egypt etc., and consequently it is not unlikely that it reached India from West Asia sometimes in the fourth millenium B.C.

The beautiful Harappan pottery was fired in kilns specially built for the purpose. Harappan kilns have been unearthed in the course of excavation at Mohenjo-daro and Lothal. Of the two kilns laid bare at Mohenjo-daro, only one is somewhat intact and conveys us a fair idea of its functioning (Mackay, 1938, pp. 62, 102 and 177). It was located in the DK area which has yielded some of the most important structures and antiquities of the Indus civilization. The kiln, of fired clay, is elliptical on plan. It is 6 ft. long 4 ft. 9 in (1.80 x 1.47 m) wide but its height could not be known as the sides were already completely destroyed. The excavator has tried to reconstruct the kiln as follows : "A pit for the wood or reed fuel was prepared. Over this was a domed compartment to hold the vessels to be baked. Communication between the two was effected by round holes in the floor of the upper chamber (Mackay, 1938). In other words, the kiln can be said to have been provided with a fire chamber below whereas the holes were obviously provided to serve as outlets for the hot gas from below. This type of kiln, known as the vertical kiln was also in use in West Asia in prehistoric times (Singer, I, pp. 392-94).

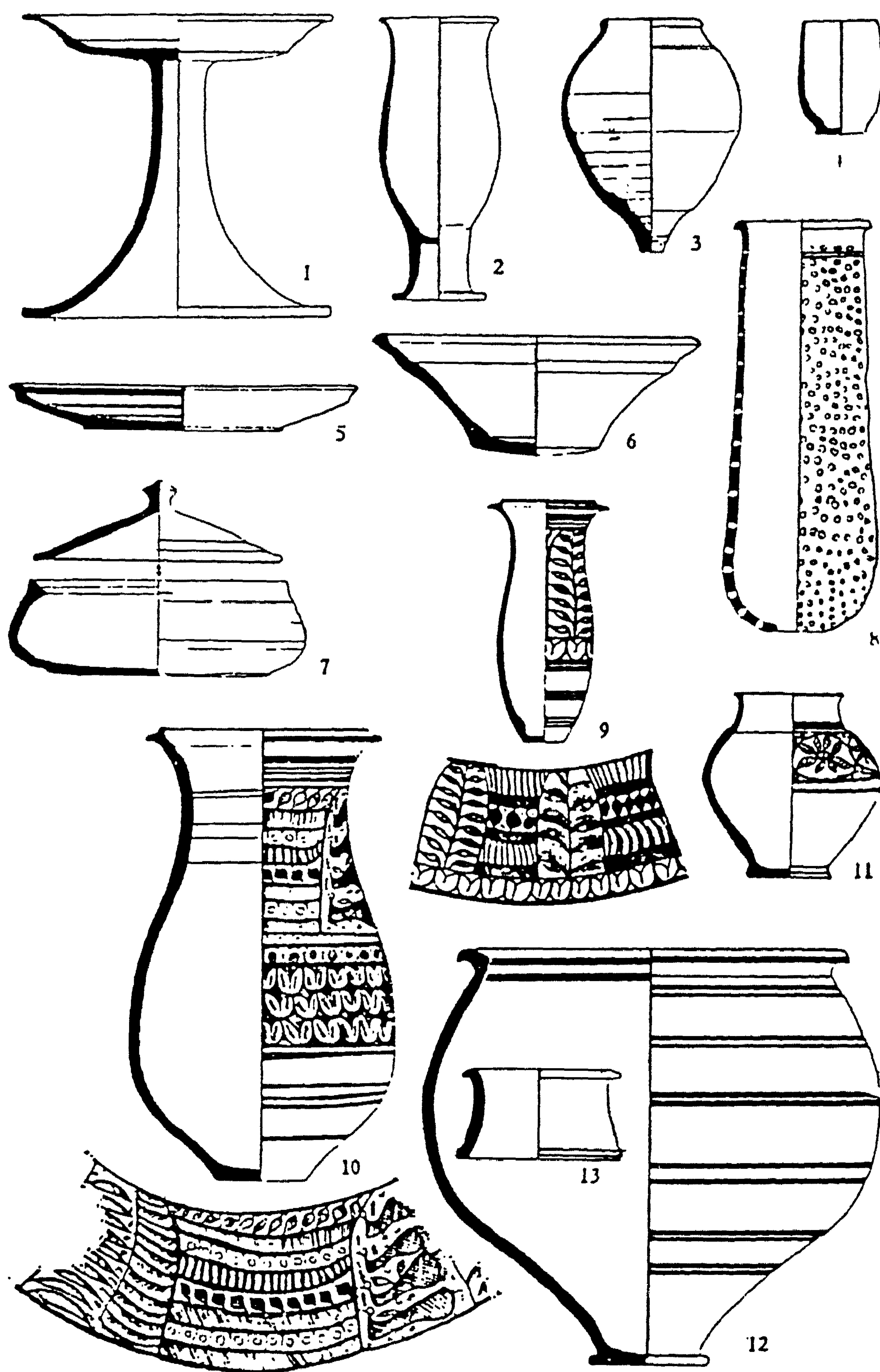


Fig.2 Characteristic Harappan pottery forms

Ochre Coloured Pottery (OCP)

The ochre coloured pottery constitutes a knotty problem in the archaeology of north India. The pottery was first found in the excavations at Bisauli, a copper hoard site in Dist. Badaun, U.P. and Rajpur Paraṣu, Dist. Bijnaur, U.P. Later in 1952 it was encountered at Bahadarabad (Dist. Dehra Dun, U.P.). Several OCP sites have since then been discovered and it has been observed that the pottery is usually found at the Copper Hoard sites in the Ganga Yamuna Doab, but the excavations so far carried out at such sites have failed to produce any evidence of Copper Hoard artifacts from stratified levels. There is thus circumstantial evidence to associate the OCP with the Copper Hoards. However, the only solitary site where both occur together in a stratified context is at Saipai (Dist. Itawah, U.P.) where the excavations have yielded a barbed harpoon of copper, a characteristic Copper Hoard type (PURA, No. 5, 1971-72, Spl no. on OCP, p.6). More evidence of this nature in future may connect the Copper Hoards with the OCP.

The OCP occurs in north India over a large area from Bahadarabad near Dehra Dun to Noh near Bharatpur and from Kathpalon near Jullundar to Ahicchatra (Dist. Bareilly, U.P.), that is roughly the present states of Punjab, Haryana and western U.P. The forms include bowls, basins and jars of various sizes (Ibid). The OCP has affinities with Harappan pottery as is evident from such forms as the dish-on-stand, basins with beaded or beaked or everted rim, storage jars and bowl-shaped lid with a central knob. However, it is as yet a moot point whether or not the OCP has been derived from the Harappan.

It may be recalled in this connection that Stuart Piggott (p. 238) once identified the authors of the Copper Hoard culture as Harappan refugees.

The enigmatic feature of the OCP is its rolled nature. It has been generally attributed to its being ill-fired, and hence it is reasoned that the ochre colour of the surface has a tendancy to rub off easily. Since both the surfaces of the potsherds are considerably rolled, it has not been possible to ascertain whether the pottery is wheel thrown or hand made. It is, however, thought that the pottery is wheel made and the peeling off of the slip has been stated to be due to its being underfired (Thapar, p. 31). However, water logging and association with river silt are also said to be the causes of the rolled nature of the pottery. Examination by B.B. Lal of the OCP potsherds have shown that the surface has completely broken down due to weathering on account of prolonged action of subsoil moisture coupled with injurious soluble salts (Sinha, p. 91). According to him, "the conditions favourable for weathering may be present in the soil itself on account of subsoil moisture containing carbon dioxide and soluble salts (Sinha, p. 91). His tests indicates that the pottery is not underfired as is generally thought by archaeologists, but that it was fired at a sufficiently high temperature in an oxidising atmosphere (Sinha, p. 92)". Lal does not agree that the rolled nature of the pottery is due to water- logging. He rightly questions : "How is it that at Bargaon, where ochre coloured pottery is associated with another red pottery, the effect of water logging is exhibited only by Ochre coloured pottery and not by the other pottery (Sinha, p. 92)".

Lal has offered a plausible explanation of the rolled nature of the OCP. In his opinion, "the pottery remained in contact with saline moisture throughout its long

period of burial in the soil. An equilibrium was established between the pottery and its saline and moist environment and there was no surface erosion or disintegration in this condition of equilibrium. Once the pottery was excavated and brought to the surface, the moisture present therein evaporated leaving the solidified salts in the pores. The crystallization of soluble salts in the new environment brought the disintegration of the pottery (Sinha, p. 95)". Lal concludes that the OCP remained exposed to atmosphere for a considerable period and consequently it underwant weathering before it was sealed by the debris of the succeeding occupants.

Chalcolithic Painted Pottery *(Central India and the Deccan)*

Kayatha Ware

The discovery of the Chalcolithic phase in the prehistory of the Deccan in 1950 has brought to light a whole new range of ceramics which is essentially painted black-on-red and its varieties. These painted pottery cultures - characterised by the use of copper and stone tools and hence the label chalcolithic are distributed in Central India and the Deccan and are datable to the second millenium B.C.

Of these, the Kayatha culture (Circa 2000 - 1800 B.C.), so named after the type site Kayatha, (Dist. Ujjain, M.P.), and the Malwa culture (Circa 1700 - 1300 B.C.) are both distributed in Malwa which roughly comprises the western districts of the present Madhya Pradesh. The former is characterised by three distinct ceramic wares viz., the Kayatha ware, the red-painte buff ware and the Kayatha combed ware (*Fig. 3*). The Kayatha ware is a study fabric represented by bowls, dishes and large storage jars. It is treated with a red wash over which designs are executed in deep purple. The pottery is of extremely fine fabric, made of well legivated clay which is devoid of any impurities. The other ware is buff coloured and bears paintings in dark red; it is also of fine fabric but is thin walled. The most representative forms in this ware is a *loṭā* with blunt carination and globular jars with outcurved rim.

The combed ware is not much different from the Kayatha ware so far as the fabric is concerned. It bears combed designs, but occasionally painted patterns also occur. The painted designs on all the Kayatha wares are linear and geometric such as lines and dashes and lozenges and triangles etc (Ansari and Dhavalikar, pp. 4-5).

Malwa Ware

The Malwa ware is a well defined ceramic which is essentially buff or cream-slipped and bears painted patterns in dark brown. At least superficially it bears some resemblance with the red- painted buff ware of the Kayatha culture. The relationship between the two, however, has not yet been established. The ceramic is extremely rich in form and painted ornamentation.

The core is somewhat coarse and the slip is considerably thick (*Fig.4*). The fossil forms comprise the typical Indian *loṭā* with a bulbous body and wide flaring mouth. But more interesting are the channel spouted-cups and pedestalled gobblets; the latter have turned up at Navdatoli only. They have significant parallels in Iran and hence they have been associated with Aryans (Sankalia, 1964, pp. 315-17). The

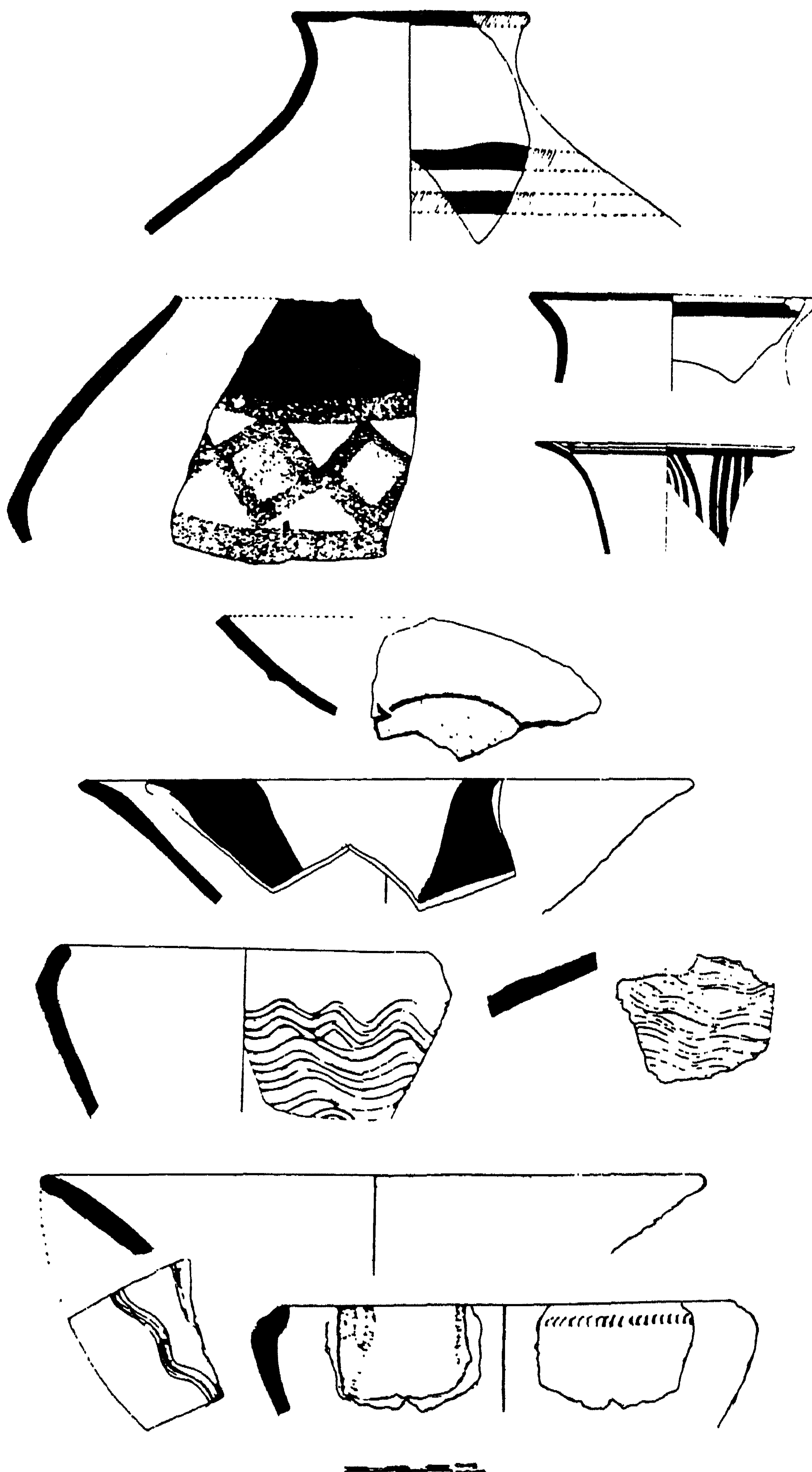


Fig.3 Kayatha pottery, 1-6 red painted buffware, 7-10 combed ware

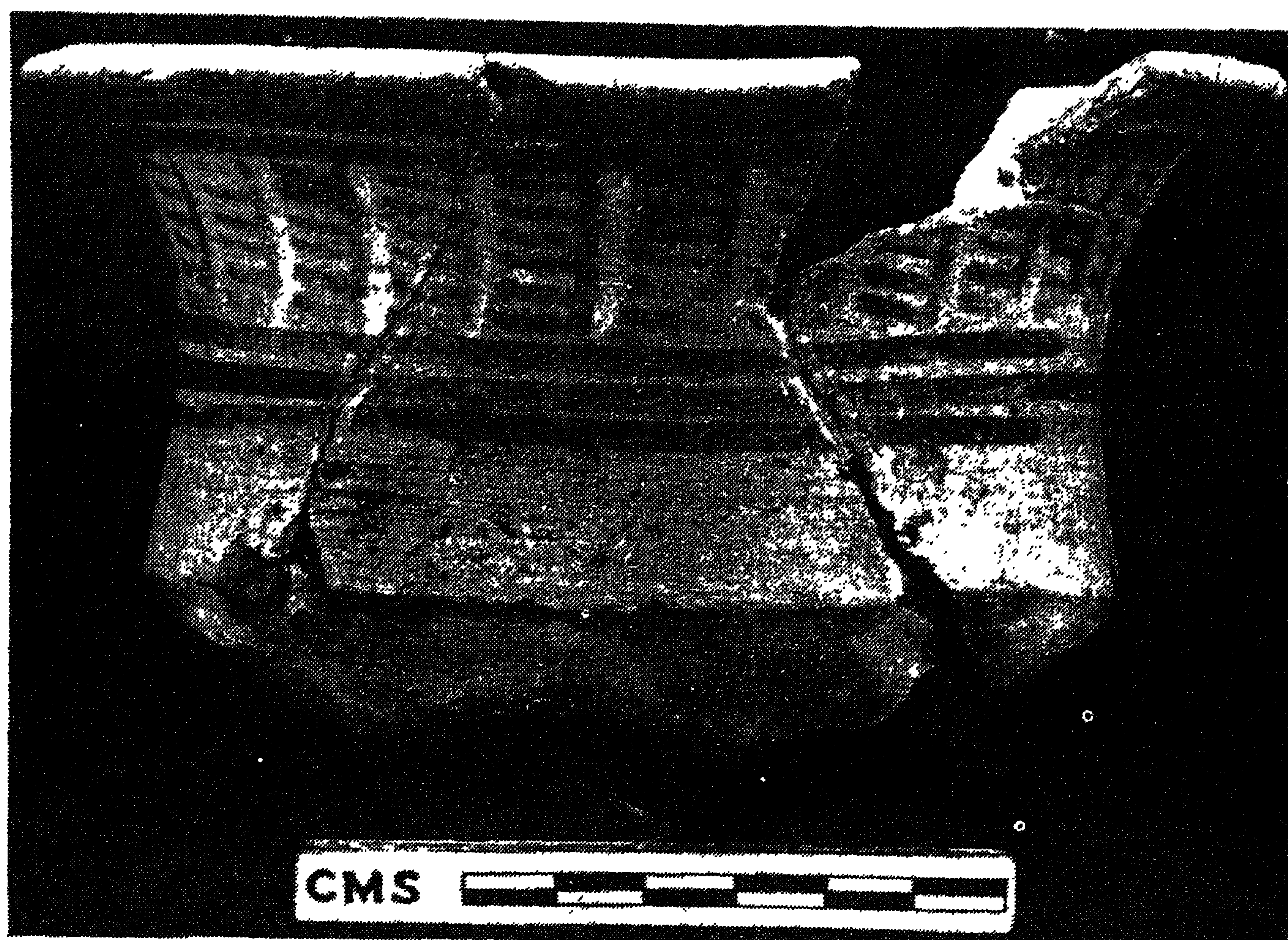


Fig.4 A Malwa ware bowl from Navdatoli (M.P.)

repertoire of painted ornamentation is quite rich and there are over six hundred motifs in all. They are primarily geometric such as triangles and lonzeges but there are many exquisitely naturalistic designs such as animals, birds, plants etc. One must agree with H.D. Sankalia who states that "Among all the painted pottery found in India so far, that at Navdatoli has given the larges repertory of designs (Sankalia, 1974, p. 457)."

Although we cannot say much about the technology of the Malwa ware, as it has not yet been subjected to scientific examination, we can have some idea of the kilns of the Malwa culture. In this connection it may be stated that the Malwa culture of Central India had spread into Maharashtra and its remains have been found in the Tapi, the Pravara-Godavari and the Bhima Valleys where it can be assigned to Circa 1600-1300 B.C. In fact at several sites, as at Inamgaon, the first settlers were the Malwa people. In Maharashtra, however, the Malwa painted pottery is of a finer fabric in a sharp contrast to the coarse fabric in its kneeler area. The vessels are treated with a wash of orange or pink and the painted designs are in black pigment.

The designs consist of linear and geometric patterns, but naturalistic motifs such as dog, deer, bull etc., are also be met with. The jar with tubular spout, which is conspicuously absent in Malwa proper, is present in Maharashtra. The Malwa ware can, therefore, be said to have undergone some change in form and fabric in Maharashtra; it resembles more that from Eran.

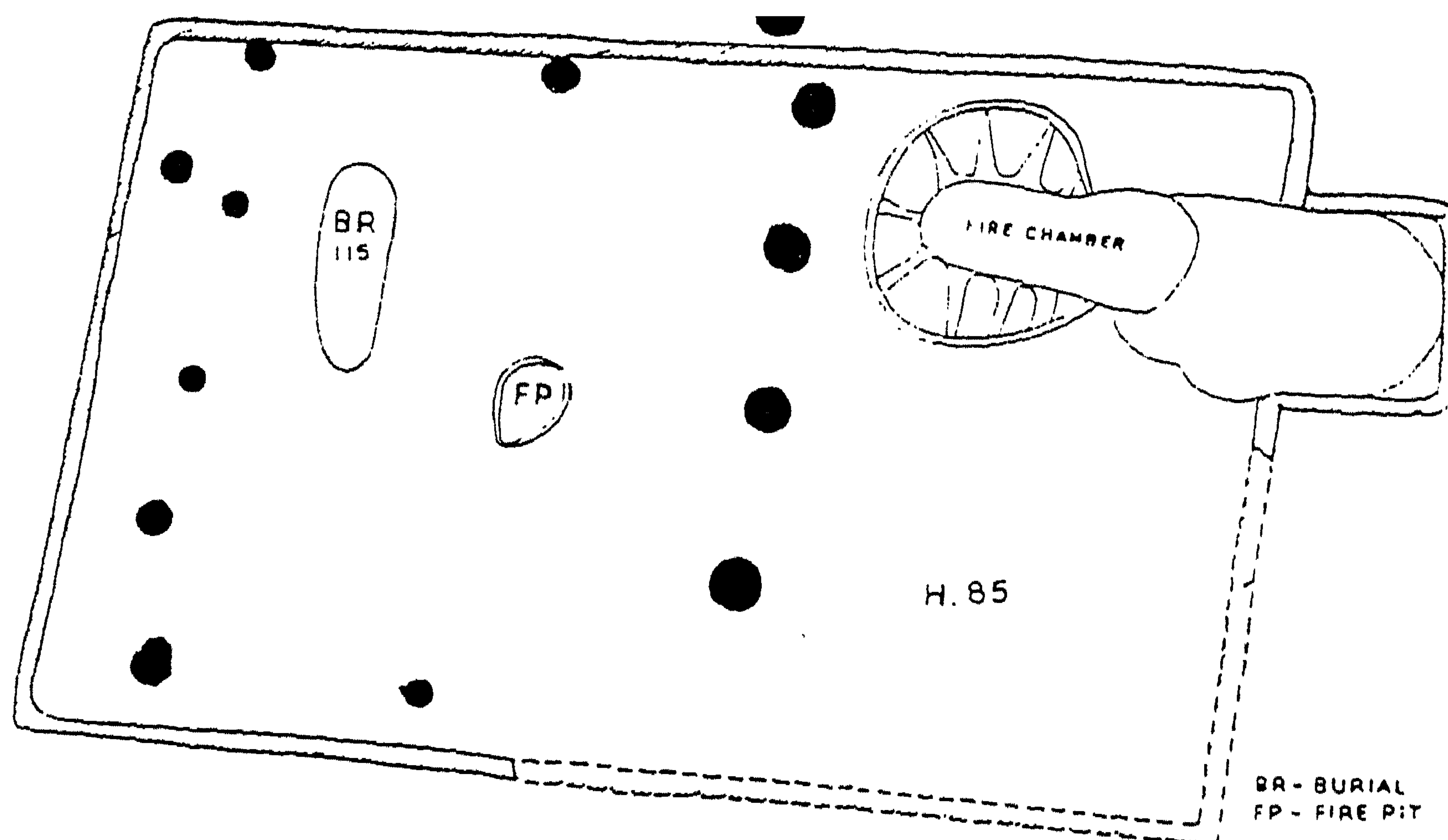


Fig.5 A pottery kiln of the Malwa period

A pottery kiln of the Malwa period (*Fig.5*) was uncovered at Inamgaon (Dist, Poona, Maharashtra). Structurally it is almost identical with that of the succeeding Jorwe period at the site which will be described later. In size, it is half of the latter. It is round (diameter, 1.55 m) with a fire chamber attached to it, and is provided with fuels for hot gas. The kiln was located in a house which could be identified as that of a potter.

Jorwe Ware

The Jorwe culture, named after the type site in Dist. Ahmednagar, Maharashtra, was accidentally discovered in 1950 but its chronological position was fixed by the excavation at Nasik where the remains of this culture were found in the lowest levels assignable to the first half of the first millenium B.C. A number of Jorwe settlements have since been excavated during the last thirty years which has increased our knowledge of the material culture of these first farmers of Maharashtra. They were spread almost all over the present state of Maharashtra save the coastal strip of Konkan on the west and parts of Vidarbha in the east. A series of radio-carbon determinations suggest that the culture can now be dated to Circa 1400-1000 B.C.

The most distinguishing feature of the Jorwe culture is its black-on-red painted pottery. It is wheel thrown and of thin to medium fabric. It is made of well levigated clay which is devoid of impurities. The vessels have a mat surface and are treated

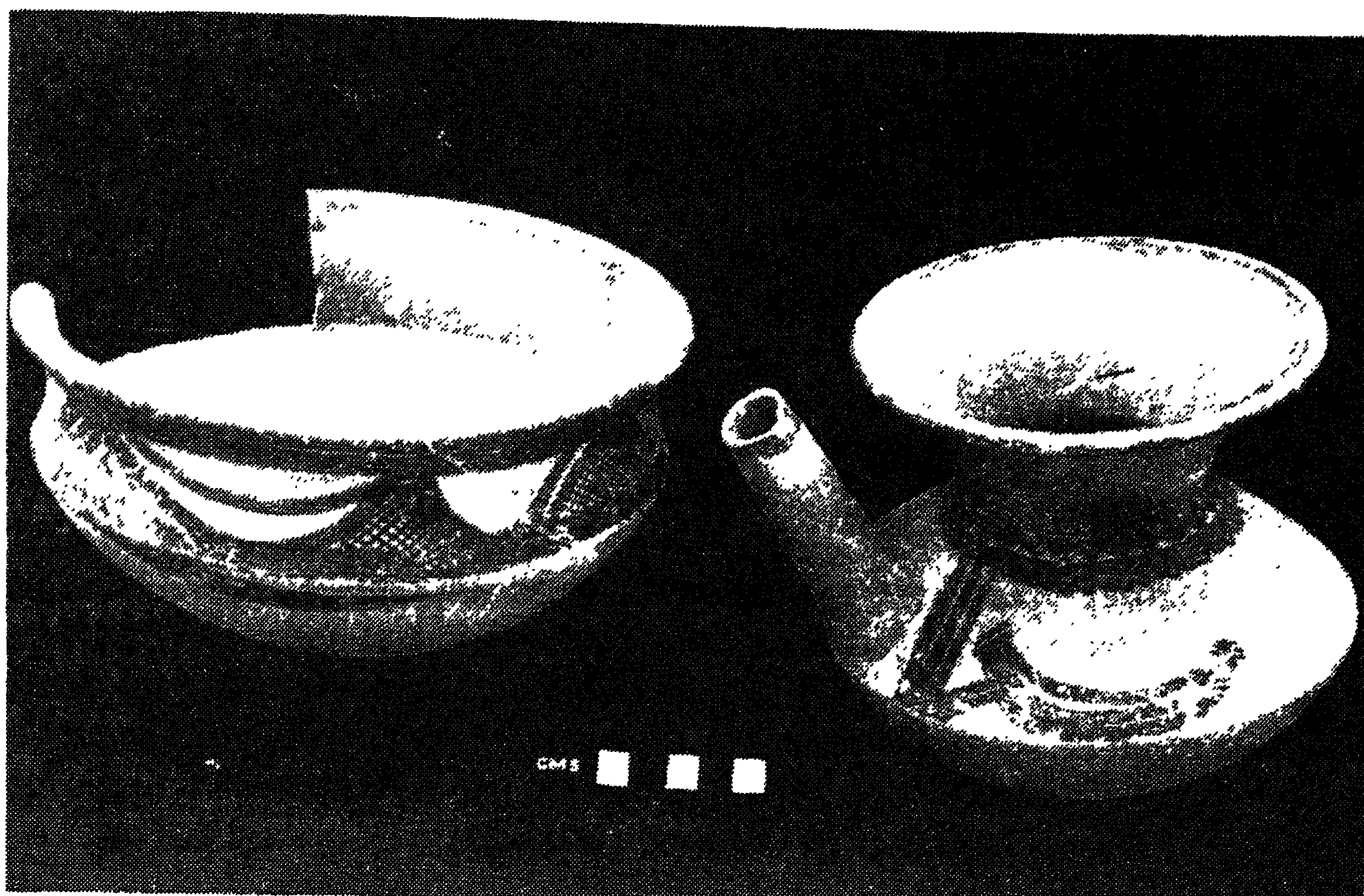


Fig.6 Jorwe ware

with orange to red wash. The most distinctive vessels are a concave-sided carinated bowl with a round bottom and a spouted jar with carinated profile and a wide flaring mouth. Besides these, there are high necked globular jars and storage jars with constricted neck and bulging belly. The painted decoration is in black and repertoir of designs is extremely limited. The patterns are mostly linear and geometric such as sets of lines, triangles, lozenges loops etc. (*Fig. 6*).

An interesting feature is the occurrence of some peculiar symbol on each and every vessel which has been taken to be the potter's mark. Associated with this is a crude handmade red/grey ware which is characteristic of the southern Neolithic.

A potter's kiln was uncovered in the course of excavations at Inamgaon (Dist. Poona). It belongs to Early Jorwe period (Circa 1400-1000 B.C.). It is like a huge trough made of clay and embedded in the ground on stone foundations(Dhavalikar et al 1988; Vol.1,pt.i,pp.255ff). It appears to have been built *in situ*. Its maximum diameter is 1.75 m and at a depth of 60 cm from the top were found clay cushions in the kiln placed over the fire chamber. These cushions are oval in shape and have a hole in the center and a groove on the middle of each side; the holes in the center obviously served as outlets for the hot gas. In the base of the kiln were flues or air ducts radiating from the center. To the north east of the kiln was the fire passage lined with stones and reaching below the bottom of the kiln where an andiron or firedog of clay was placed. It is rectangular in shape with projecting corners and curved upper sides for supporting firewood. At the time of baking pottery the firewood on the andiron was lit and the resulting hot gas would he passed above through the flues and holes and grooves in the clay cushions. It is thus a unique kiln

which has so far no parallel within the country or even beyond. But in principle it is akin to those from Indus cities which were provided with several holes for the hot gas (Mackay, 1938). The clay and iron inside the fire chamber has, however, parallels in West Asia where they have been dated to Circa 2700-200 B.C (Braidwood,Jr, pp. 371-73, Fig.290-91,A&B)

A coarse variety of the Jorwe ware has been found recently in the excavations at Inamgaon and at a few sites in the Bhima valley. The coarser fabric is due to a lot of gritmixed as the tempering material and the tradition of painting is also on the decline. This late Jorwe ceramic is datable to Circa 1000-700 B.C.

Lustrous Red Ware

The Lustrous Red Ware, a ceramic derived from the Harappan, is almost contemporaneous with the Jorwe ware. It occurs in Gujarat in the post-Harappan levels (*AI*, WS. 18-19, 1963, p.136, fig.34, pl.XXII). The lustre, according to B.B. Lal is the result of smooth burnishing with pebbles of haematite when the pot was in the green state. This left a fine powder of iron oxide securely adhering to the surface. The pot was then fired in oxidising conditions.

Technology of the Chalcolithic Painted Pottery

All the ceramic wares of the Bronze Age/Chalcolithic period which are red wares painted with black designs with its variants such as the Harappan, the OCP, the Kayatha-Malwa, Jorwe and the Lustrous Red ware fabrics are the products of identical technology. The red colour of the surface is due to the presence of iron compounds in clay which impart the red colour to the pottery when fired under oxidising conditions.

The temperature required for such red wares is around 800^0F. The bright red slip such as that on the Harappan pottery is said to be due to ferric oxide and the presence of manganese oxide in the pigment has made them black or dark brown.

The designs were executed with manganiferous haematite and hence they have turned black in firing. Even today the potters of north India produce black-on red painted pottery by using the same materials.

Painted Grey Ware

The painted grey ware (PGW) is one of the most characteristic ceramic of the middle Gaṅga Valley (Tripathi). Technologically it has proved to be the most enigmatic pottery, and culturally too the PGW problem has been vexing the brains of scholars since its discovery in the forties. The pottery was first noticed in the excavations at Ahicchatra (present Ramnagar, Dist. Bareilly, U.P.) but the chronological position was later clearly established at Hastinapur (Dist. Meerut, U.P.) which was excavated by B.B. Lal (1954-55, pp.5-151) of the Archaeological Survey of India in 1948-49. Since then a number of PGW sites have been discovered. They suggest that the culture was spread in western U.P., Haryana, eastern Punjab and eastern Rajasthan. Recent exploration by Rafiq Mughal of

Pakistan have brought to light a few PGW settlements in the erstwhile Bahawalpur state, on the fringe of Thar Parkar desert of Pakistan (Lal, B.B. *Ibid*). Similarly the misconception regarding the superficial identity between the PGW and the grey ware from Thessaly in Greece has to be removed. The author had occasion to visit the neolithic site in Thessaly viz., Sesklon and Dimini whence the grey ware has been reported. It should be remembered that in Greece the pottery occurs in Neolithic levels which are now dated in the fifth millennium B,C. and is entirely different in form and fabric.

Nevertheless B.B. Lal (*Ibid*) is inclined to attribute the authorship of the PGW to the Aryans of the Mahabharata period. It is also important to note that the PGW is a Iron Age Culture.

The PGW is a wheel turned pottery of extremely fine fabric. It is ash grey in colour and is painted with designs in black which are mostly linear such as groups of lines, sigmas, spirals etc. It is represented by bowls with vertical sides and dishes with incurved rim. The core of the pottery is uniformly grey but the surface colour sometimes changes into light orange as is evident from the specimens from Ahicchatra. Although the technique of producing the ceramic was not clearly known till recently, the experiments by K.T.M.. Hegde have been helpful in understanding it (Hegde, 1975, pp. 187-190). He observes: "After painting, the pots were stacked in a saggar. The gaps between the pots in the saggar were probably filled with goat droppings or some other carbonaceous material.......and sealed the saggar in a kiln, gently raising the temperature of the kiln to about 800^0C and retaining the kiln at that temperature for some time, at least over twelve hours. In this way red ochre pigment was reduced into magnetite and the evenly baked PGW was produced "(Hegde, 1975, *Ibid*). Thus according to him, the black pigment of the painting is magnetite. The black slipped pottery which is found associated with the PGW at many north Indian sites, also belongs, technologically to the same class as the PGW. The black slip, according to Hedge, was produced by the application of liquid clay containing finely ground red ochres burnishing it and then firing the ware under reducing conditions (Hegde 1975,p.198)

Northern Black Polished Ware

The Northern Black Polished Ware (NBP) is perhaps the finest of the Indian ceramic wares of the ancient period (Krishna Deva and Wheeler, pp. 55-59).It is a most distinctive pottery which displays a high degree of technological excellence. As the very name signifies, it is essentially a pottery of northern India but has a very wide distribution in terms of space. It is found almost all over of north India, having its focus in the ancient Magadha region of Bihar, that is the area around modern Patna. It is found in Bengal and also in Central India but rather rarely in Gujarat and Maharashtra. A few specimens have also turned up as far south as Amaravati near Guntur in Andhra Pradesh. Outside India it occurs in the present day Pakistan and even beyond in eastern Afghanistan. In terms of time it can be assigned to a period from 600-200 B.C., broadly but the recent C-14 dates place the beginning of this ware slightly later in 4th century B.C.

Although the bulk of the pottery is black, that is having a black slip, we come across specimens of different colours ranging from steel grey to bluish black and even red and silver and golden NBP has also been reported. Sometimes reddish blotches are seen on vessels. Painted NBP has been reported at Sravasti. The pottery is made of extremely fine clay and the core is usually grey. It is treated with a thin slip which bears extremely high, almost mirrorlike polish. It is represented mostly by bowls with straight sides and dishes with incurved rim and the ware is thus akin to the PGW in form and fabric. It is, therefore, not unlikely that it may perhaps represent the further stage of technological development of the PGW. Besides, there are lids with flat terminals and carinated handles. The mirror-like polish of the NBP has proved to be extremely enigmatic and has so far eluded all attempts at solving the mystery. Several scientists have offered their own explanation based on their experiments, but there does not seem to be any general agreement within sight.

Among the early attempts to explain the technology of the NBP, the noteworthy is that by Sana Ullah. His analysis revealed that "the slip on the pottern contains about 13% ferrous oxide which is responsible for the black colour. The original slip was evidently a highly ferruginous (possibly consisting of a finely levigated mixture of clay and red ochre) ground in water and applied to the surface of the vessel before firing.

The black colour was doubtless developed by the action of reducing gases formed in the kiln. The polishing might have been done before or after the firing. The coating is not a siliceous glaze (Sana Ullah, p.58).

Yet another authority has suggested that the pottery was fired at a very high temperature in saggars, as was done in the case of the PGW. This is very likely in view of the similarity in fabric of both the PGW and the NBP (Rowson).

Bimson, an expert of the British Museum, has also explained the technology of the ceramic. In his option, cited by sir Mortimer Wheeler, "The unfired pots were dipped in a suspension of ferruginous inorganic material, probably resembling red earth and that after firing to a temperature of 800° the kiln was sealed so that the pots cooled in a reducing atmosphere. The mineralogical identity of the "red earth" has not been discovered and the main problem, namely the precise nature of the surface layer, still remained unsolved (Wheeler, 1959, p. 30).

According to K.T.M. Hedge, the mirror-like polish of the NBP ware "was produced by an application of liquid clay, quite similar to that employed for manufacturing the body of ware, but which in addition to levigation was carefully further shifted and cleaned for the purpose of reducing heavier particles like felspar, quartz and limestone present in the clay by means of suspending and stirring the clay in water. This clear clay liquid was then peptized by the addition of an alkali containing material" (Hedge,1962, pp.159-161; 1966, p.623). The clay solution thus prepared and treated with a little alkali gives a black shiny slip when fired in reducing conditions.

The Alkaline material used by the NBP potters, according to.Hegde, was *sājji māṭṭi*. He produced the NBP in his laboratory using ground red ochre and *sājji māṭṭi* in clay (Hedge, 1975, 188). H.C. Bharadwaj, on the basis of his experiments, observes that "We may tentatively suggest that the black colour of the slip is

materially on account of carbon and our experiments and observations do not substantiate the presence of magnetite or ferrous silicate." (in Sinha, p.19)

Although there does not seem to be any general opinion about the technology of the NBP, K.T.M. Hegde's observations are significant. He observes: "It appears that the potters were experimenting. They first used red ochre as the painting medium to decorate the Painted Grey Ware. In the second stage they ground it with clay and *Sājji māṭṭi* to produce the black slip on the Black Slipped Ware. In the third stage, they ground it with clay and *sājji māṭṭi* to produce the lustrous slip-glaze on the Northern Black Polished Ware. All the there wares were baked in a reducing atmosphere. The NBP was their highest achievement (Bharadwaj, 1975, p.190).

Mughal Glazed Ware

This is essentially a ceramic with its surface treated with a glaze. It occurs almost all over the country in the levels assignable to the mediaeval period. The ceramic is rather coarse in fabric and is usually represented by bowls and dishes, and sometime small pots. In a majority of cases the glaze is pale green in colour in limitation of the Chinese Celadon.

Although it has not yet been scientifically examined, the glaze can be said to be the result of the use of powdered glass in the solution. The glaze was applied when the pot is in the leather hard condition. In several cases we notice that the glaze has a tendency to run on.

A coarser fabric of the glazed ware has been reported at Hastinapur (Dist: Meerut, U.P.). It is of whitish colour and has a sandy core (Lal, 1954-55,p.71). Only two types, bowl and dish, are represented in this ware (*Fig. 7*). An interesting feature of this ware is the ring base which is common to almost all the vessels. The designs, both geometric and floral, are painted in blue or chocolate brown and sometimes

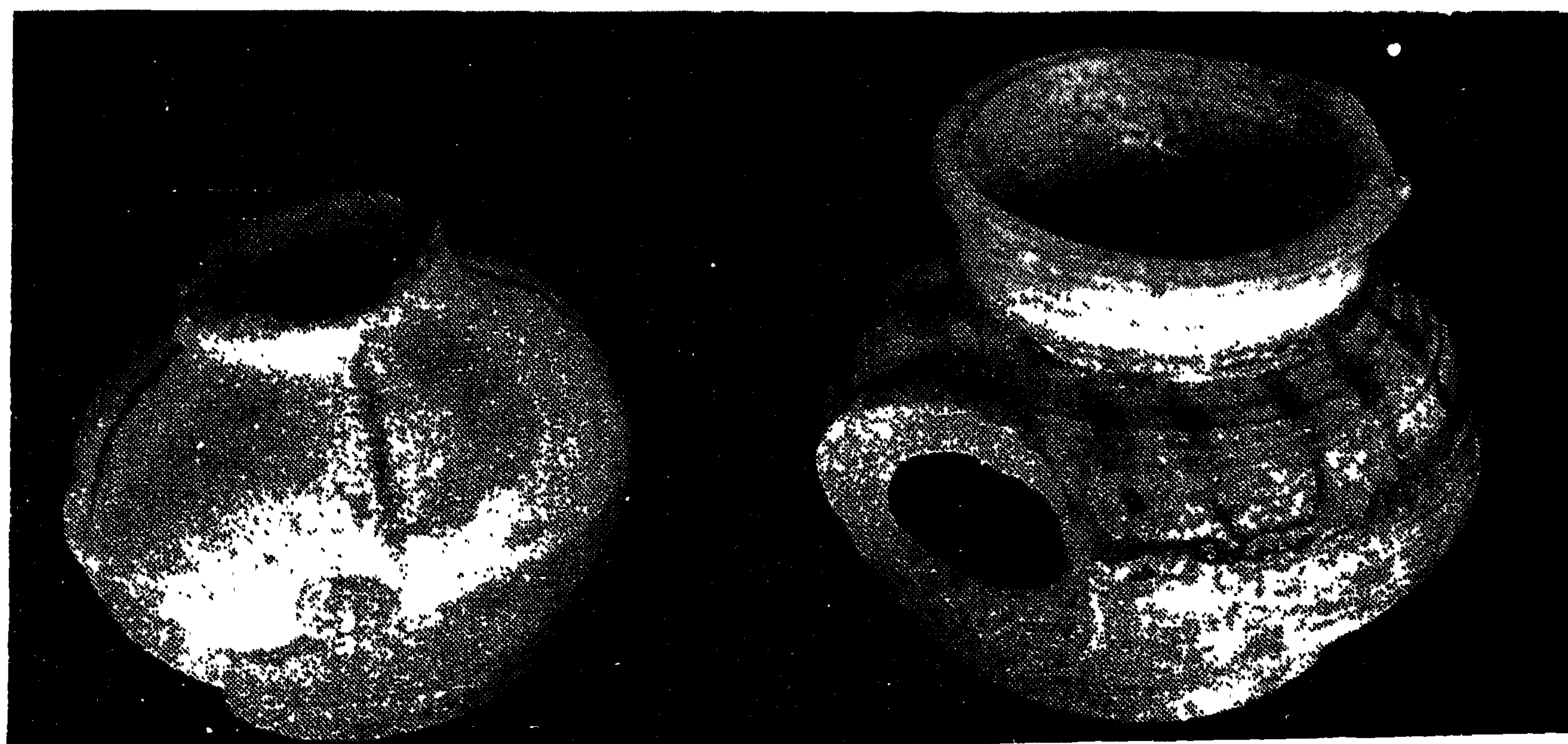


Fig.7 Mughal glazed ware

white too. Similar pottery is found in Afghanistan where it is known as the 'Timurid Ware' and the Indian variety appears to have been imported from there (Hethington, pp.15ff). But it should be noted that the technology of glaze has a very high antiquity in India; even the Harappans produced a type of glazed ware Sankalia, 1970,p.11). In the post- Harappan period, no glazed ceramic worth the name was produced in India. The glazing technique was perfected by the Chinese and the credit of medieval glazed wares in India ultimately goes to them.

Chinese Ceramics

The Chinese ceramic wares occur in different parts of the country in early medieval levels. They can be divided into two groups viz., i) the Celadon and ii) the Porcelain. The former also is a glazed pottery but can be distinguished on account of its greenish colour. It is roughly coloured with crackled surface. The other variety is usually white coloured with paintings in blue, sometime stamped with the mark of the manufacturer (*Fig. 8*). However, in terms of time, the Celadon ware has an earlier beginning going back to 7th century A.D. Both the wares occur in India and have a datable value.

The name Celadon is generally supposed to have been based on the colour of the costume of a character, Celadon, in *L'Astree*, a 17th century French romance. But this is rather incorrect for according to some, the name is derived from 'Salahdin' a Sultan of Egypt who sent forty pieces of this ware to Nur-ed-din, Sultan

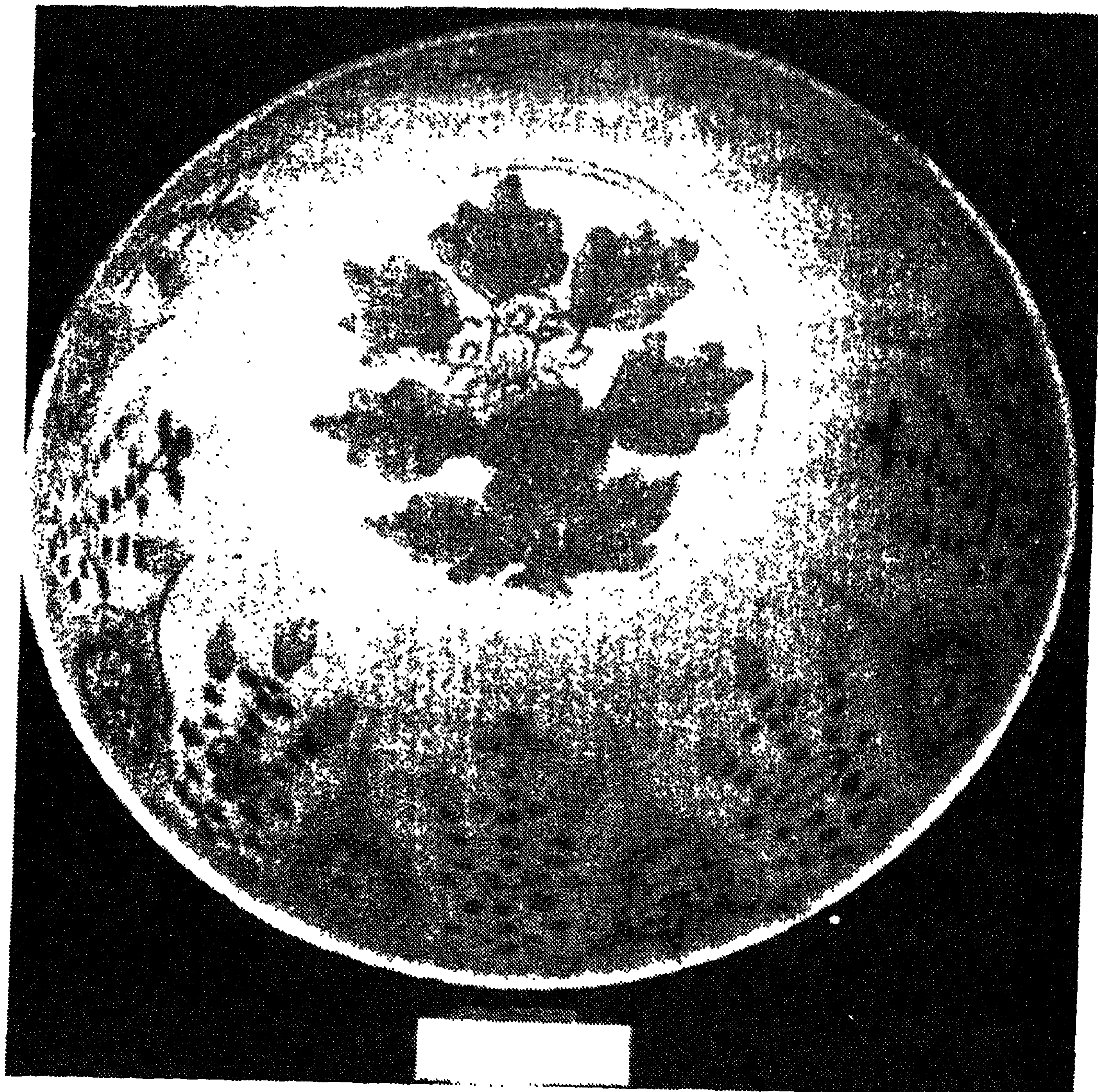


Fig.8 Chinese porcelain, a bowl from Ahmednagar (Maharashtra)

of Damascus in 1171 A.D. (Savage, p. 40). The ware was much in demand because of its supposed medicinal properties as also for its aesthetic quality.

It was Marco Polo, the great Venetian traveller, who described the manufacture of the Chinese porcelain which he witnessed the country of Kubla Khan. He gave it the name porcelain because it resembled the shells of the *genus porcellana* (Savage p.38). The Chinese, however, call it *tzu* because of the metallic sound it produces when struck. The ceramic is made of a mixture of Kaolin (meaning 'high ridge', a place where it was found; it is the same as China clay) and *pai-tun-tzu*. The latter was used in powdered form for glazing as early as third century B.C. Later it came to be used in the body of the ceramic (Honey, p.13). The Celadon was made locally mostly in the Cheking province of China. It was already in production before the end of the Tan Dynasty (618-906). Much of it was specially made for export and its distribution began before A.D. 883, the date of the abandonment of Samarra on the Tigris, where the ceramic has been found. Al-Biruni (A.D. 973-1048) refers to the export of the wares to India. Marco Polo (1288) who gave them the name porcelain, also describes the route of export from China to India through Sumatra - Martaban (Burma) from where it was transhipped to the Malabar coast, Gujarat, Cambay and Malwa (Savage, p.95)

The Chinese Celadon was held in high esteem in the medieval world probably because it resembled jade and was therefore thought to possess the qualities of the latter such as smooth, resonance and durability. But the Sultans in West Asia perhaps attached to it the quality of revealing poison in food when placed in it - a characteristic of jade. This would explain the export of mostly dishes and bowls of Celadon ware to West Asia and also to India under the Mughals. This belief in the magical properties of the Celadon have been recorded in 13th century by the philosopher Āṭ-Ṭusi (1201-74) in a book on precious stones written for Halaku, the Mongol conqueror of Baghdad, to instruct him in the appreciation of the gifts and ornaments presented to him. At-Tusi states that poison in food placed in a Celadon vessel would cause it to sweat, and that powdered Celadon porcelain would act as a tooth salve and would check nose bleeding. In other forms of the legend current in India and Persia, it is affirmed that "if poison is present, the dish will crack or change colour or the food will change its smell" (Honey, pp. 95-96)

The Chinese porcelain is usually represented by bowls and dishes, all with foot rings. The vessels of China clay were fired into porcelain at about 1300^0C. With the help of a less decayed and more fusible form of the felpathic material called by the Chinese *pai-tun-tzu*. This latter is the same as *petuntse* in the 18th century French phonetic equivalent. It actually means "little white rocks", because the material was sent to the potter in the form of small bricks after being pulverised and refined (Honey, p.13). The ware was placed in saggars or otherwise supported by firing setters and was fired in a continuous tunnel kiln which was a Chinese invention.

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Glass

H.C. BHARADWAJ

Origin of glass is shrouded in mystery and it is difficult to pin point the exact place and date of its birth. Pliny the elder, attributes the discovery of glass making to the Phoenician merchants of 6th century B.C. who made a chance discovery while cooking meal on the sandy shores of the river Belus near Ptolemias. Lacking stones to support their pots they used lumps of natron, which combined with sand and turned into glass under the impact of heat of the kitchen fire. This legend has wide popularity.

However, archaeological studies have clearly proved that ancient civilization of Mesopotamia, Egypt and India made various siliceous and glazed materials including faience (glazed siliceous ware), glazed pottery and glass. Earliest faience and glazed steatite from Mesopotamia is datable to 5th millennium B.C. Faience has powdered quartz core with an over glaze, which is a soda-lime-silica glass, and is isotropic in nature (Marshall 1931).

There is controversial evidence of glass from Ancient Egypt datable to 3500 B.C. found at Naqada. However, glass was definitely known and deliberately made by Mesopotamians and Egyptians during 3rd millennium B.C.

Archaeometric studies reveal that glass gradually evolved through experimentation by Early man with various siliceous materials with the help of pyro-technology. Vitreous paste, frit, faience, glazed pottery - the cousins of glass, are the evolutionary stages, finally culminating in glass making. It is the first product of composite pyro-technology.

Whether the Harappans i.e. people of the Indus civilization knew glass making is debatable. However they made bangles, beads and other objects of faience (glazed siliceous ware) and glazed pottery in 3rd millennium B.C. They knew the art and science of colouring glazed layer both blue and red with cupric and cuprous copper (Bhardwaj 1985).

Earliest Glass Objects

Recently glass bangles in black and sky blue colour have been reported from Bhagwanpura (Haryana) in an overlap phase of Harappans and painted greyware people, datable to 2nd millennium B.C.(Bhardwaj 1987).

Important Archaeological sites yielding glass and the nature of Glass

Archaeological excavations have brought to light glass objects mainly beads, bangles, seals and ornamental pieces from sites including Atranjikhera, Hastinapur, Ropar, Alamgirpur, Ahicchatra, Sravasti, Kausambi, Rajghat, Kopia, Ujjain, Maski, Maheshwar, Prakash, Brahmagiri, Kondapur, Amravati, Nevasa, Tripuri Nasik, Patliputra, Candravalli, Sisupalgarh, Candraketugarh, Arikamedu, Nalanda, Bellary, Kolhapur etc *(Fig 1)*. The earliest objects are confined to beads and bangles of brown, black and dark green colour. The limited chemical analysis show that these are low in silica. Soda is the predominant alkali, though potash is also present. Iron is the main colouring agent. Use of chromium as colourant is reported from Atranjikhera. Annealing is supposed to have been done. In general the objects are confined to beads and bangles. A piece of a glass container is reported from Atranjikhera, district Etah,(U.P.) datable around 1000 B.C. Atranjikhera evidence is an exception (Agarwal 1983).

Around 600 B.C., there was proliferation in glass industry. Glass beads and bangles are reported from a large number of sites of N.B.P. ware phase i.e. Mauryan period. In

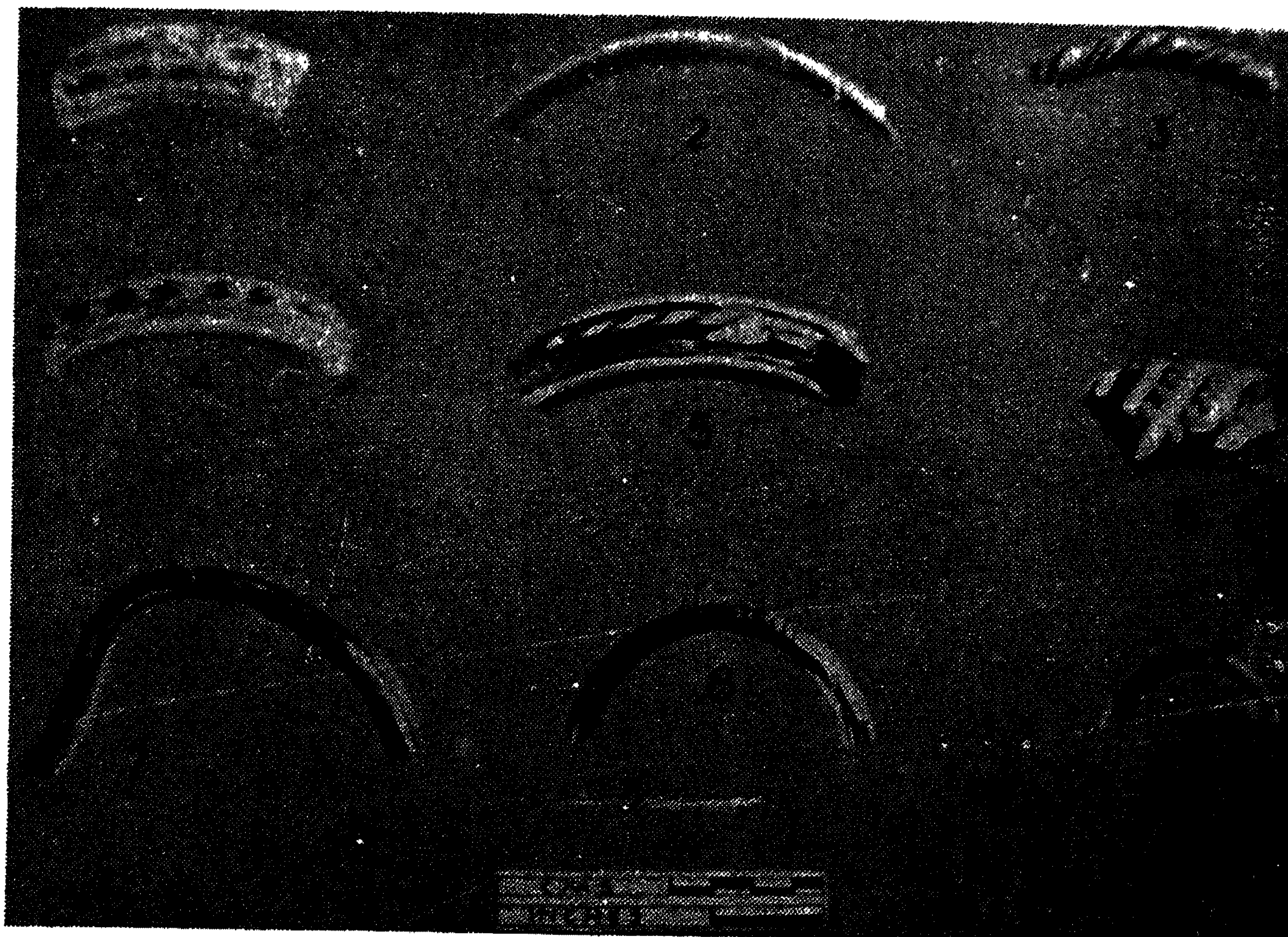


Fig.1. Glass bangles from Prakash, Dt. Dhulia, Maharashtra. (Courtesy : H.G.Dikshit, History of Glass). No.1 Pd.II (700 B.C. - 100 B.C.) Nos.2-7 Pd.III (100 B.C. - A.D.600) Nos.8-9 Pd.IV (A.D.600 - A.D.1100)

addition glass seals and ear-reels are also reported. Another feature of this period is the use of copper red glass for beads. Recently a broken copper red glass tile *(Fig 2)* has been reported from Khairadih (Dist. Basti) excavated by B.H.U.

The colouring agents are confined to ferrous and ferric iron and cuprous and cupric copper.

Nature of glass objects during the First Millennium B.C.

In the first half of the period glass was a scarce material and the objects were confined to glass beads and bangles.

In the second half of the first millennium B.C. glass industry made some advance. Important finds of Mauryan period include glass seals and sealings with Brahmi characters. These are reported from archaeological sites of Kumrahar and Bulandibagh. The colours are confined to blue and green. These are cast in moulds. A glass seal of 2.4 cm square and 10 mm thick, amber in colour with the figure of an elephant is reported from Maheshwar (Madhya Pradesh). A similar seals has been reported from Ujjain. Three glass seals, locally manufactured have been reported from Taxila (Dikshit 1965 and 1969). Glass discs and ear reels are the other objects of interest. Black glass discs with legend in Brahmi character in red glass are housed in the museums of Patna, Banaras and Allahabad *(Fig 3)*. These discs have been fabricated by pulling large size glass canes. Ear reels in good



Fig.2. Glass Tile - Copper Red Glass from Khairadih c. A.D.100. (reproduced from Ancient India nos.20-21)

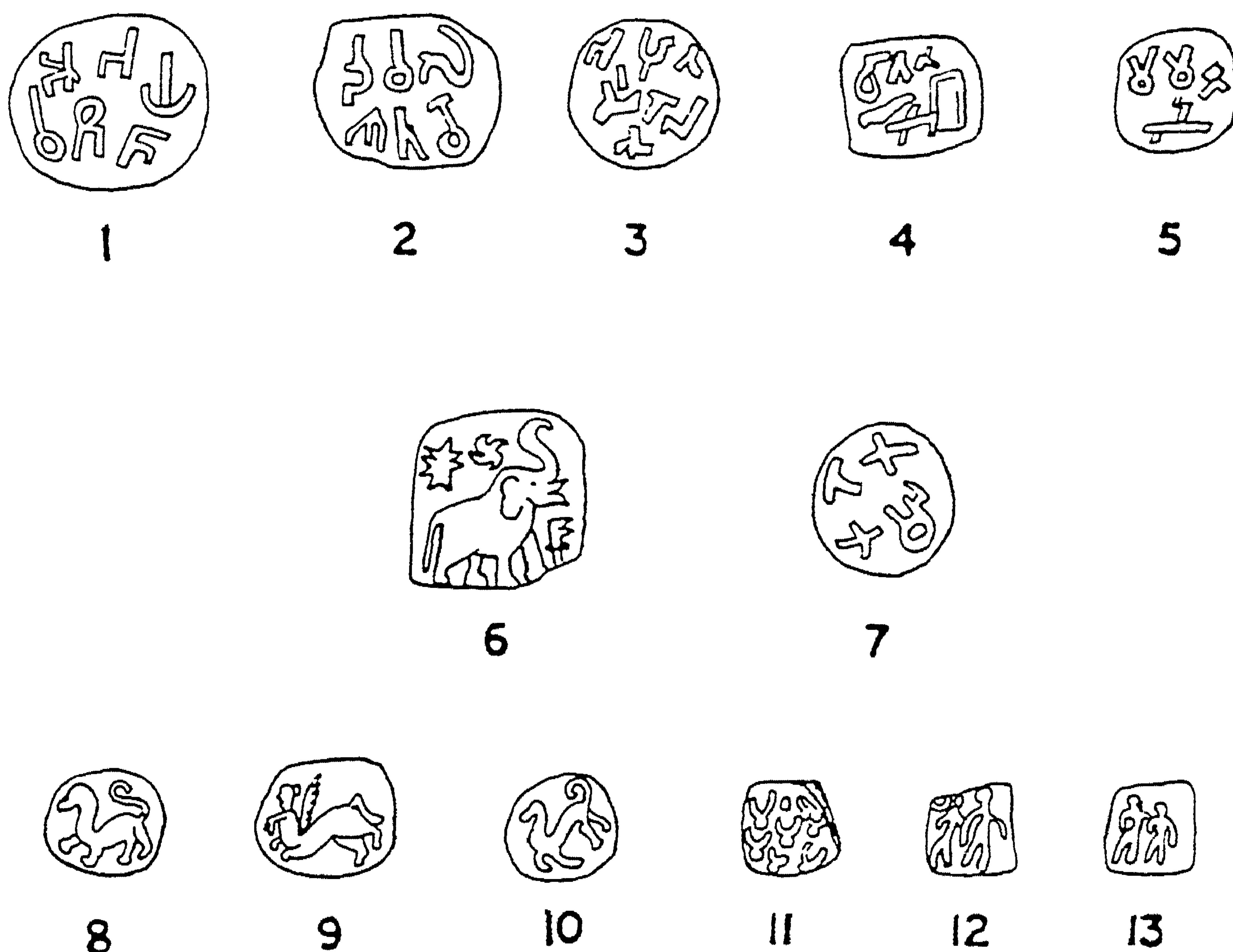


Fig.3. Early Indian Glass Seals and Sealings - 1-5 Patna (Excavations at Kumrahar and Bulandibagh) 6. Maheshwar 7. M.G.Dikshit Collection. 8 to 13 Taxila Excavations

number have been reported from Ujjain, Maheshwar, Nasik, Kaundinyapur (Vidharba). These are coloured white, vermillion, opaque blue and green.

Glass Technology During Early Centuries of Christian Era

Early centuries of Christian era has been an affluent period in glass technology in India. During this period glass became more popular. On the one hand there was import of Roman glass objects as a part of Mediterranean trade with India and on the other hand local glass industry imbibed new techniques of the west.

Glass flasks from Taxila from Saka Parthian levels look to be of Mediterranean origin. Glass objects from Arikamedu near Pondicherry also show that *(Fig 4&5)*. Roman glass objects were imported. These include glass bowl and mosaic tablet of millifiore glass having floral device in the centre.

Evidence of progress in local glass industry is available in the form of large glass tiles 10.25" square and about 0.2" thick. These are in various colours and were used for laying the *pradakṣiṇāpath* of the monastery of the Dharmarajika stupa at Taxila.

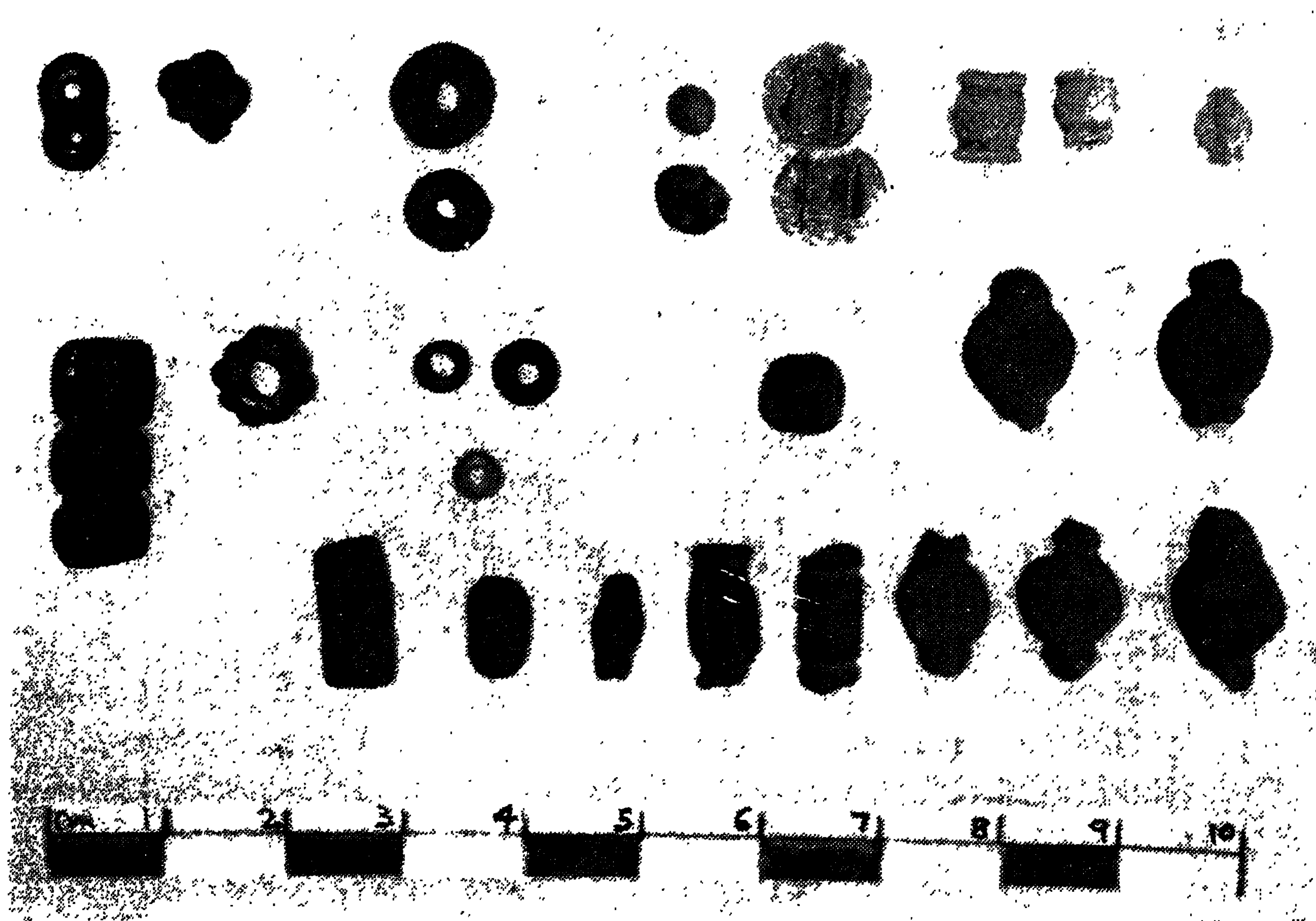


Fig.4. Coloured Glass beads from Arikamedu, old French Exacavations, (Courtesy : Pondicherry Museum)

Gold foil beads represent another advance of this period. Glass industry at Kopia (Dist. Basti) belongs to this period. From here a block of 120 lbs of unworked glass was recovered. In Deccan also the glass industry made head way during Satavahana period *(Fig.6)*. This is attested by the nature of glass objects i.e. Nevasa (Dist. Ahmadnagar in Maharashtra) has yielded 12 rims of glass containers in emerald green, Persian blue and yellow colour. Ter (Dist. Osmanabad in Maharashtra), has yeilded two flasks, one coloured blue and the other coloured to imitate agate. These have been made by the core process. Devnimori in Gujrat and Amreli in Kathiawar have yielded fragments of glass bottles and loop handles of a bowl. Paithan (Maharashtra) has yielded rim fragments of a glass container in cobalt blue colour. Important articles and publications on various aspects have been mentioned in the bibliography in the end.

Manufacture

Ingredients for glass in early days were river sand, crude natron or plant ashes and some colouring matter. Calcium carbonate was not added separately but particular sands were selected which contained lime. Such river sands are common in India.

Production of Glass involved two stages. In the first stage sand and crude natron were heated at a temperature of 750°C when they were converted into frit. In the second stage the frit was converted to glass by heating it in crucibles upto a temperature of around 1100°C, till glass had become homogenous and clear.

When finished, the glass was either poured straight into the mould for casting seals and slabs or it was poured in bits at a time and rolled into thick rods which were drawn into canes or strips.

Table 1 — Colouring Agents used

1.	Red and Liver red	Cu_2O - Cuprous oxide
2.	Brown	Fe_2O_3- Ferric oxide
3.	Chocolate(opaque)	Cu_2O+Fe_2O_3, - Cuprous oxide and Ferric oxide
4.	Black	Ferri-sulphide/Ferrous oxide
5.	White	SnO_2-Tin oxide
6.	Green - Bottle green	Mixture of CuO, FeO and Fe_2O3
7.	Bluish green	Fe_2O_3+CuO
8.	Turquoise Blue	CuO (Cupric oxide)
9.	Deep Blue	CoO (Cobalt oxide)
10.	Yellow	Fe_2O_3 (Ferric oxide)
11.	Violet	MnO (Manganese Oxide)

Characteristic Features of Ancient Indian Glasses (see Table 2)

1. Ancient Indian glasses from the very beginning show very good state of preservation and have not devitrified. It may be concluded that their chemical composition was quite compatible for producing good quality of glass. (Lal 1952)
2. There was practice of annealing of glass objects.
3. Many glass objects are translucent rather than transparent. This indicates their technological limitation. Either the melt was not completely molten and some of the batch materials remained unfused. That higher temperature required for plaining was not attained.
4. Ancient Indian glasses have relatively high alumina, higher than 3.5. - 4% and low lime content rarely exceeding 5% and low magnesia.
5. Early Indian glasses whether from P.G.W. Levels or N.B.P. phase are soda - lime - silica glasses.
6. All glasses contain iron oxide. Probably it was present in the batch materials as an impurity.
7. Lead, antimony, barium, tin and phosphorus are not present in early indigenous glasses.

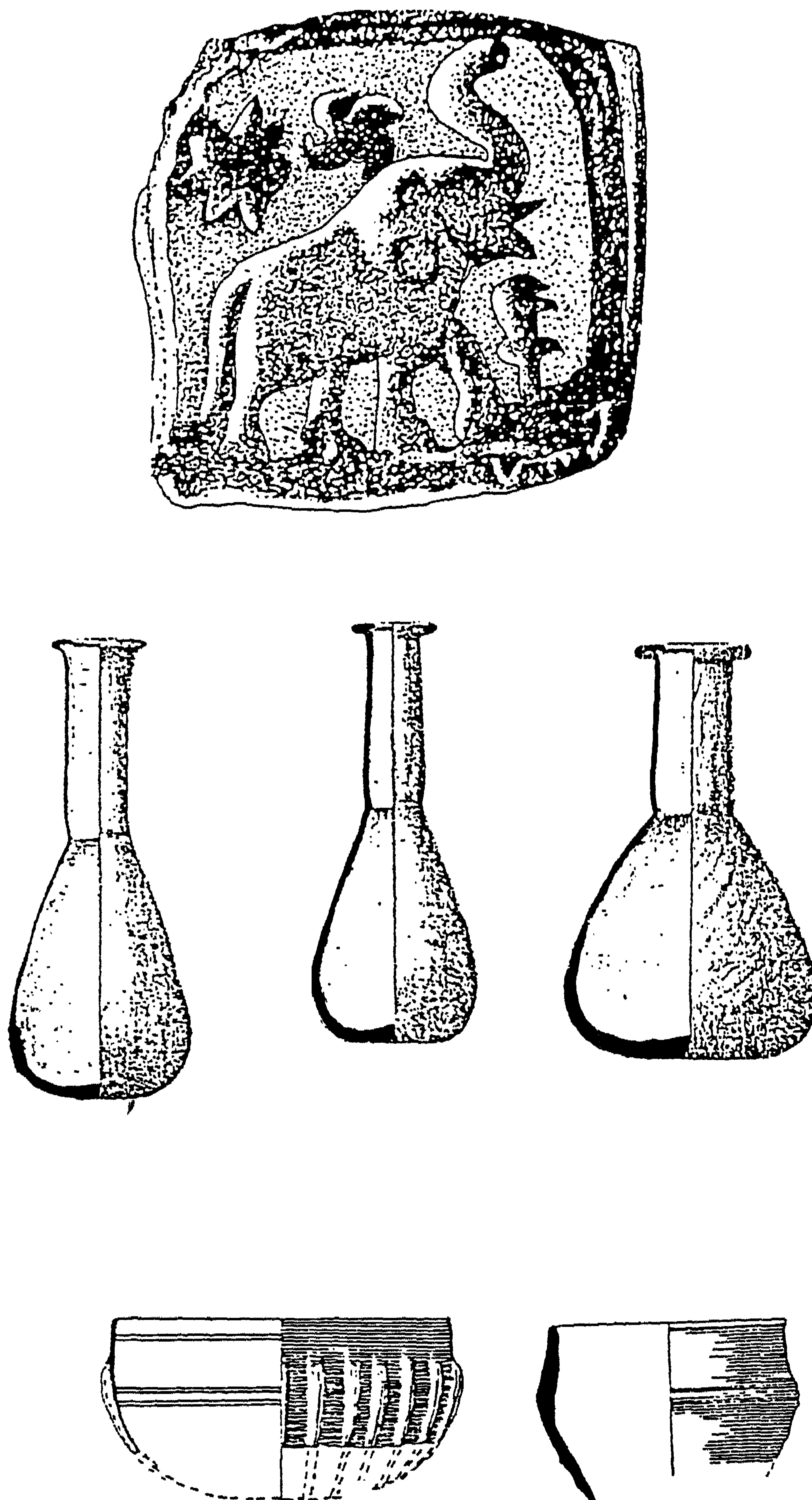


Fig.5. (1) Detailed view of glass seal from Maheshwar (c. 300 B.C.). (2) Glass Flasks from Sirkap (Taxila): Śaka-Persian levels (c. First century A.D.). (3) Glass Bowls from Arikamedu of Roman origin (First century A.D.)

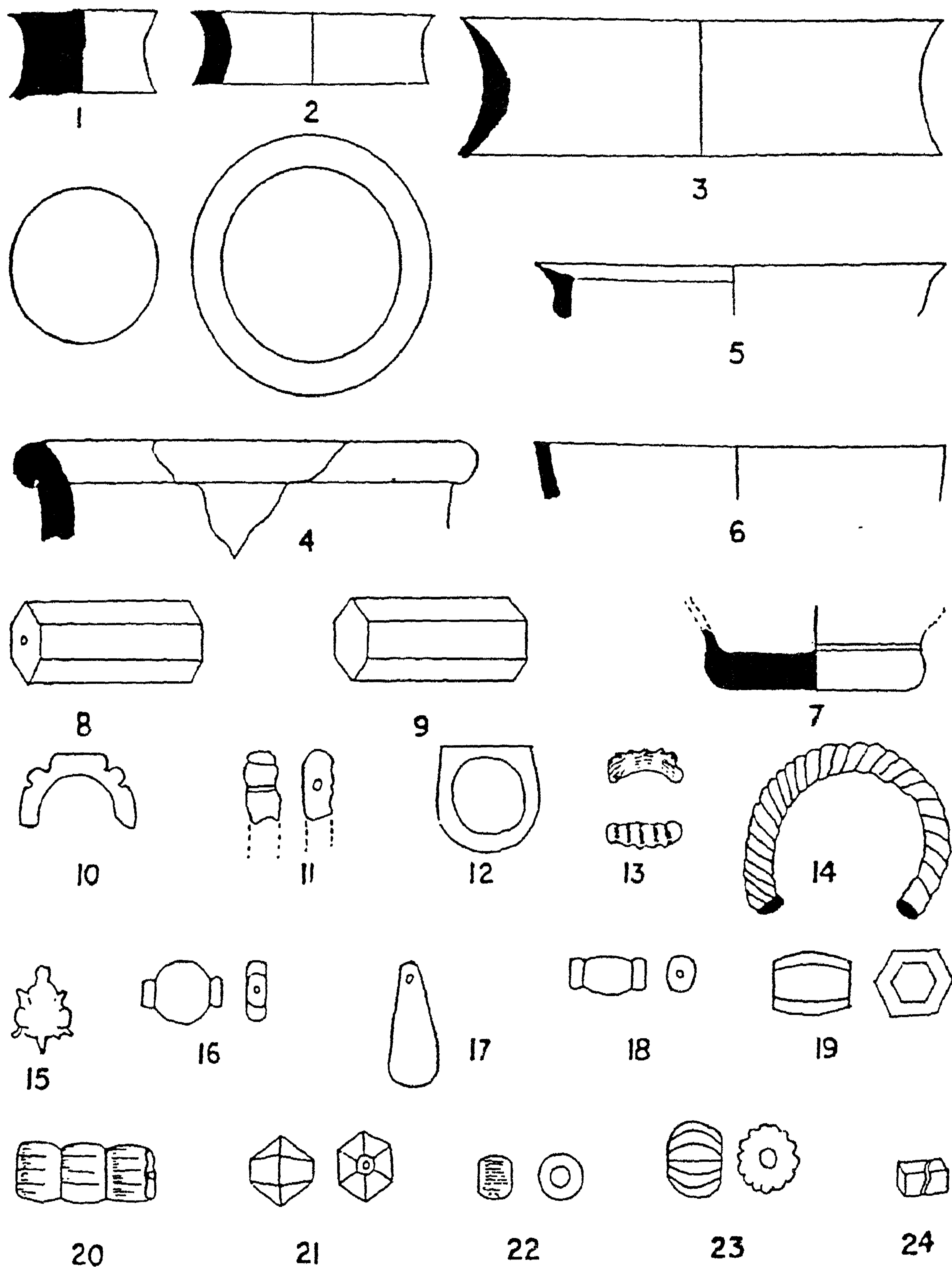


Fig. 6. Glass Objects from Śātavāhana sites in the Deccan (1:1) Cross Sectional View (reproduced from H.G.Dikshit, 1969). (1 to 23): Cross Sectional View of Glass objects from Satvahanas. Details of Glass objects (cross-sections); 1 and 2 Ear-red from Ter 3. Bangle from Ter 4. Fragment of bottle from Pai. 5. Rim of Glass vessel from Nevasa. 6 and 7 Rim and solid base of Glass from Ter 8. and 9. Large Perfect cylinder hexagonal glass beads from Sopara. 10. Fragmentary ear-ring from Ter. 11. Head of perforated Kohl-stick from Nevasa. 12. Ring from Nevasa. 13 and 14 spirally wound glass bangles and rim from Ter. 15. Blue glass amulet imitating Tri-ratna from Ter. 16. 18-24. Various shapes of Glass beads from Satvahana site from Deccan including Ter, Nasik, Paithan, Nevasa, Prakash, Sopara etc. 17. Glass ear ornament

Table 2 — Percentage Composition of Some Ceramic Materials and Glasses from Indian Archaeological Sites

Sl. No.	SiO_2	Al_2O_3	Iron Oxide		Cr_2O_3	MnO	Copper Oxide		CaO	MgO	Alkalies		SnO_2	Sb_2O_3	PbO	P_2O_5	Total
			FeO	Fe_2O_3			Cu_2O	CuO			Na_2O	K_2O					
1.	84.66		6.31	-			-	0.97	1.40	-	5.48	-	-		-		100.00
2.	91.07	2.44	-	-			1.98	tr	1.28	tr	-	2.08	-	-	-		98.85
3.	54.28	19.63	8.70	-		0.13	-	-	9.63	4.39	3.43	-	-	-	-		100.19
4.	56.96	3.62	-	4.46	1.09		-	-	7.00	3.75	17.55	4.09	0.89	-	1.06		100.47
5.	65.01	2.28	-	9.67			5.27	-	4.08	0.49	13.05	-	-	-	-		100.00
6.	39.79	-	2.45	-			5.31	-	2.81	-	10.02	0.57	0.22	-	38.93		100.10
7.	61.32	-	1.70	-		0.26	-	-	9.74	1.64	20.26	-	-	5.08	-		100.00
8.	58.12	5.74	-	1.74		0.17	-	-	8.85	4.01	16.74	4.83	-	-	-		100.20
9.	59.56	0.05	-	5.40		0.06	-	1.82	6.54	4.34	14.19	2.41	-	-	4.23	1.36	99.96
10.	73.62	1.38	-	3.84		5.01	-	-	1.96	0.30	1.30	12.78	-	-	0.07		100.26
11.	61.76	14.77	0.82	5.07		0.04	-	-	2.29	2.13	9.73	4.12	-	-	-		100.73

Descriptions Of The Samples

1. Carnelian Blue Slab, Mohenjodaro (2300 B.C.)
2. Dark red Faience, Mohenjodaro 2300 B.C.
3. Black Bangle, Mohenjodaro.
4. Glass piece, P.G.W., Dark Green, Atranjikhera
5. Opaque Red Glass Bead, Rajghat, N.B.P., 600 B.C.
6. Haematinum Strip, Taxila, C. 300 B.C.
7. White opaque Glass, Taxila, C. 300 B.C.
8. Amethyst Glass fragment Taxila C. 300 B.C.
9. Green Glass, 100 A.D. From Ahicchatra.
10 Deep violet Glass from Arikamedu.
11 Glaze, Kusana period Khokrakot

Colouring Agents

(i) From the Harappan period onwards copper (both in cupric and cuprous form) has been used to obtain various shades of blue, green and opaque red in conjunction with iron.

(ii) Use of manganese is restricted and has been reported from glasses from Kausambi (1. 42%) and Taxila glasses have upto 0.34%. Glasses of violet colour do not seem to be of indigenous origin. Such glasses as reported from Arikamedu and Ter look to be of Roman origin. Use of 0.10% MnO in glasses containing 2.5% Fe_2O_3 is reported for making colourless glass at Kopia.

(iii) Use of Cobalt : Its earliest use in India is attested in glass beads from Rajghat datable to early centuries of Christian era (1st-3rd century A.D.) and subsequently cobalt is also reported from glasses from Mason. The percentage reported varies from 0.01 to 1.90%.

(iv) Colour mechanism of copper-red glasses of Indian origin : Indigenous Cu-red glasses are free from lead and have been coloured red with substantial addition of copper and iron oxides (Bhardwaj 1970).

(a) The indigenous copper - red glasses reported from Rajghat, Kausambi, Nalanda, Ahicchatra etc. show complete absence of lead in contrast to Assyrian red glasses which have high content of lead (about 22%).

(b) another peculiar feature of Indian copper-red glasses is high content of iron oxide (9.67% in Rajghat, 9.82+7.01 in Nalanda and 9.16 in Assam glasses).

(c) Most of the Indian copper-red glasses have very high percentage of cuprous oxide e.g.: 5.27% in Rajghat, 9.13% in Assam and 10.89% in Kausambi.

(d) In contrast, glasses in other parts of the Old World have in general low content of iron oxide which is generally limited from 0.75 to 3.26%.

(e) However, cuprous oxide in very early copper-red glasses e.g.. XVIIIth dynasty Egyptian 1400 B.C., Tel-el-Amarna, and 8th-7th century B.C. Assyrian glass from Nirmud have 13% cuprous oxide.

Foreign Elements in Indian Glasses

By and large, glass industry in ancient India has been indigenous and limited to making glass beads and bangles. This limitation has been due to short supply of alkalies.

Beads look to have been exchanged or brought from one country to another and in this light we find quite a number of glass beads which look to be of foreign origin. In this connection mention may be made of:

1. Taxila (now in Pakistan) was once a province of Achaemanian empire, conquered by Cyrus and it is very likely that quite a few glass objects found from Taxila excavations are of foreign origin. Presence of substantial amount of lead in some of these glasses is a pointer in this direction. Use of antimony and tin also confirm this (Bhardwaj 1979).

2. Potash glasses with high content of silica have been reported from Ter, Kausambi, Arikamedu etc and these also look to be of foreign origin - probably Roman.

3. Tripuri has yielded 3 glass beads (datable to circa 200 B.C.- 200 A.D.) the chemical composition of these beads shows the occurrence of barium in conjunction with lead. This is a diagnostic combination of Chinese glasses of the Han Period. This strongly suggests that these beads are of Chinese origin and attest to Indian and Chinese contacts around 200 B.C.-200 A.D. (Bhardwaj 1984).

Dating value of Glass

The question is whether it is possible to pin point any characteristic features so as to date the glass finds of archaeological origin. The answer is that there is some potentiality: provided glass beads from various horizons of archaeological excavations are analysed and diagnostic features underlined. At present state of our knowledge, a the following features can help in dating:

(i) Iron is the only colouring agent in P.G.W. levels. Chromium has been recently reported from the same levels but this is a solitary evidence.

(ii) Copper (both Cu+ and Cu++) is the main colouring agent along with iron which is always present, mostly as an impurity of the raw materials.

(iii) Use of manganese both as decolouriser and as a tinctorial agent starts in the beginning of Christian era.

(iv) Use of cobalt is first noted from archaeological levels datable to 1st to 3rd century A.D.

So on the basis of their presence or absence one may be able to date the archaeological levels.

Methods of Fabrication

A variety of Glass objects e.g. beads, bangles, seals, tiles, bowls and flasks have been reported from archaeological remains. Of these beads are the commonest.

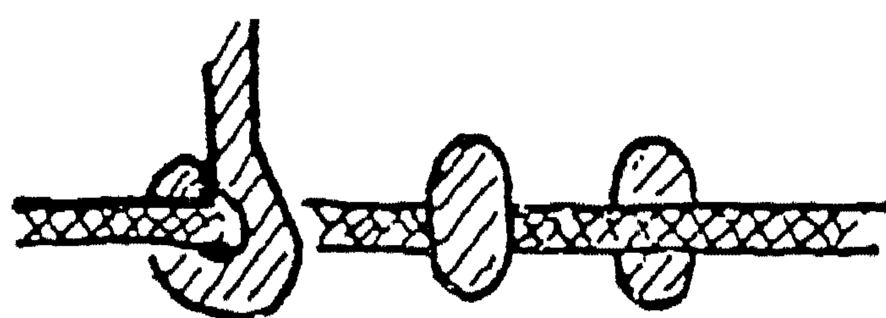


Fig.7. Simple-wound bead (from Dikshit, 1969). (Courtesy Dikshit, 'History of Glass'.)

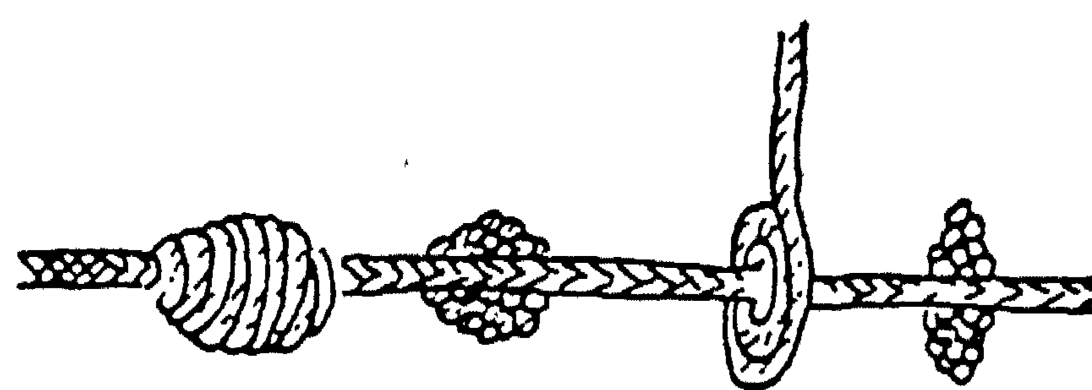


Fig.8. Multiple-wound bead (from Sen et al., reproduced from monograph on Glass, by Sen, INSA).

Beads are named differently on the basis of their fabrication and design e.g. wire wound, multiple wound, drawn out beads, cane glass beads, beads made on spoke or hand perforated beads, pressed beads, folded beads and decorative beads like eye beads, gold foil beads, flowered beads (millifiori beads) and composite beads etc.

Bead Making: The glass in molten condition was stirred with an iron bar and the mass of molten glass is gathered at its end. Another craftsman pulls out this gathered mass by fixing another iron bar to it. He pulls it quickly by running, resulting in the formation of long glass rods with average thickness of 15 mm. Glass tubes were also made similarly but the gathering was provided with an air cavity and tubes were drawn out from the gathering with a blow iron. To start with beads would have been made singly by hand by winding thin glass threads round a copper wire and breaking off the thread after each bead *(Fig 7)*. Beads from glass tubes were made by drawing out the glass tube to the required diameter and then cutting it into beads.

Having made the glass rods and canes and tubes of the requisite size the beads were made by winding the softened glass rod around wire, the thickness of which varied according to the desired perforation of the bead. Beads were made either by single or multiple winding and they were fire polished and were turned around the fire to give the desired shape *(Fig 8)*.

On cooling the beads were taken off from the wire without any difficulty due to greater contraction in the thickness of the wire. Multiple cane beads were fabricated by pulling out bundle of glass canes together and giving them desired shape *(Fig 9)*. Uniform surface was obtained by heat treatment. Beads were also made on spoke or were obtained by perforating semi-molten dropping of glass. Special beads like eye bead were made by highly skilled worker by spreading layers of different glasses on a matrix resembling the shape of eye. There is a design of eye surrounded by white matrix. Gold foil beads were made by sandwiching a gold foil in between two semi molten halves of the glass bead. Composite beads were made by adding an intermediate layer of white glass in between coloured glasses and then moulding them by twisting.

Bangle Making: In the simplest method the craftsman dips the *aṅkuri* (iron hook) into the molten glass and takes out each time a small ball of glass sufficient for a single bangle. This ball is wound up on the end of an iron spit giving it the form of a thick ring which is squeezed with the help of a dagger shaped tool known as a

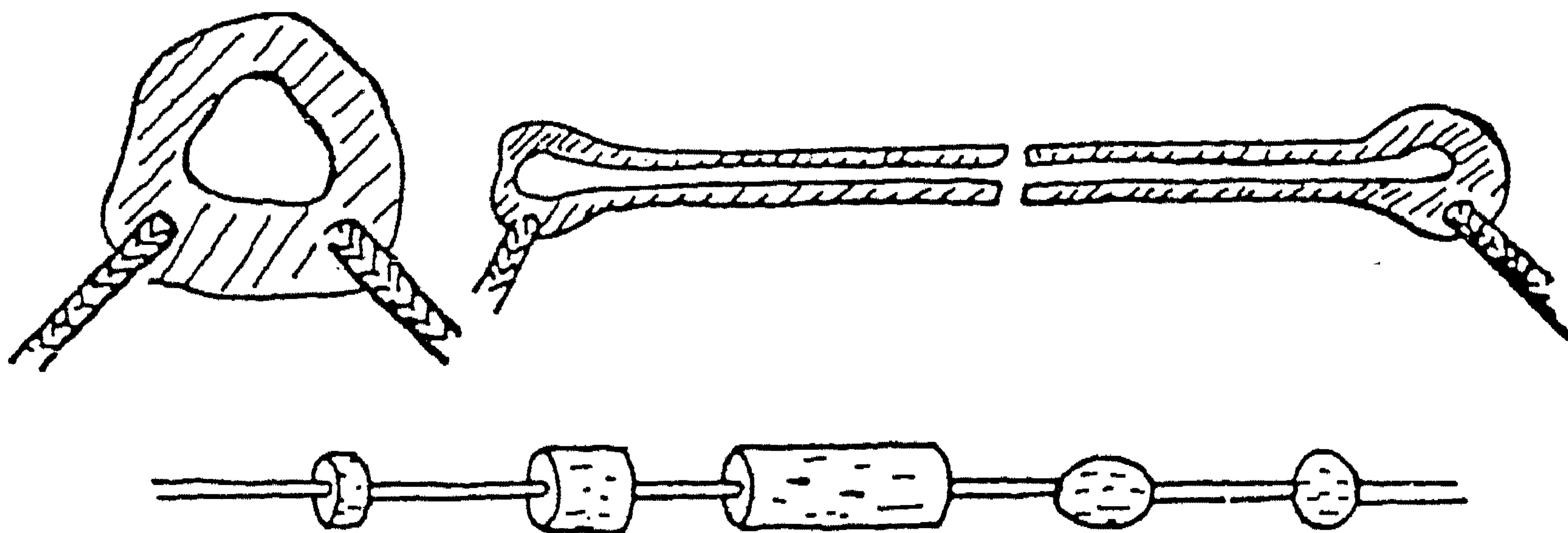


Fig.9. Drawn beads (from Sen et al., reproduced from monograph on Glass, by Sen, INSA).

mallahe - till it is cool. The ring is detached with the help of iron wire (*bandhana*) and is transferred to tapering clay cone (*kalbut*) which is processed in the furnace and spun rapidly and the glass ring over the clay cone is moved on to enlarge to the required size and is then slipped off and cooled.

Making of Hollow Wares by Core Techniques: Hollow wares as evidenced from Devnimori, Amreli, Ter etc look to have been made by core technique. A stick or a rod with conical end was coated with a ball of sand held together by cloth bag. This was either dipped into molten glass and immediately taken out or thin canes of glass in semi-molten condition were wound around the core and fire polished. In both the cases, the core was removed on cooling and hollow ware was produced.

Moulding of Glass Objects: As in the case of metal casting some glass objects were also prepared by casting in clay, sand stone or siliceous moulds. The molten glass was poured into the mould. Glass tiles, seals, and some bangles were made by casting them in moulds.

Glass Blowing Process: Though glass blown objects like glass flasks from Taxila are reported but these look to be imports. Blown glass objects seem to have originated around first century B.C. in Rome. Blowing was done either in a mould or free blowing. In mould blowing, gathering of required size was taken on the blow iron and blown a bit and introduced into the bivalve mould and then blown to fill the mould. In case of free blowing a bulb of glass was blown and shaped by marvering or with the help of a handled board *(Fig 10)*.

Early Centres of Glass Manufacture in India

On the basis of the recovery of glass lumps, slags and crucibles used for glass manufacture, Kopia and Ahicchatra in U.P., Nevasa in Deccan and Arikamedu in the South look to have been centers of glass manufacture in antiquity (Roy and Varshney 1953).



Fig. 10. Evidence for the tube-drawing process: Opaque red glass, tubes and knots. From Casal's excavations in Arikamedu (Courtesy, Pondicherry Museum). (Reproduced from monograph on Glass, by Sen, INSA)

Tools used in fabrication of Glass objects

Unfortunately there is very little information on early glass making tools Archaeologists have not been able to lay their hands on glass making tools. However Dobbs (1895) and Halifax (1892) have reported on the pre-industrial glass making tools used by the craftsmen in India. Some of these tools are illustrated in *Fig. 11*. The tools include various rudimentary types e.g. stirrer, pontil, clay cones, blow pipes, iron shears, tongs, trowel and marver, as follows.

I. *Rods of different shapes & sizes*

(a) *Śikha*: A long iron rod meant for stirring the molten and semi-molten glass.

(b) *Tokklā*: An iron rod with thick butt and tapering point.

(c) *Sāreṇḍī*: A straight iron rod used for manipulating blown bubbles of glass.

(e) *Citarṇa*: An Iron rod used for providing zig-zag shape to bangles by twisting the molten glass.

(f) *Saragañjana*: A long tapering rod of iron fitted with a wooden handle and it is used for separating bangles in semi- molten state from the clay cone. A smaller and thinner variety of *Saragañjana* was known as *Bandhana*.

II. *Kalcul, Karculi*: This is an iron ladle used for dishing out molten glass.

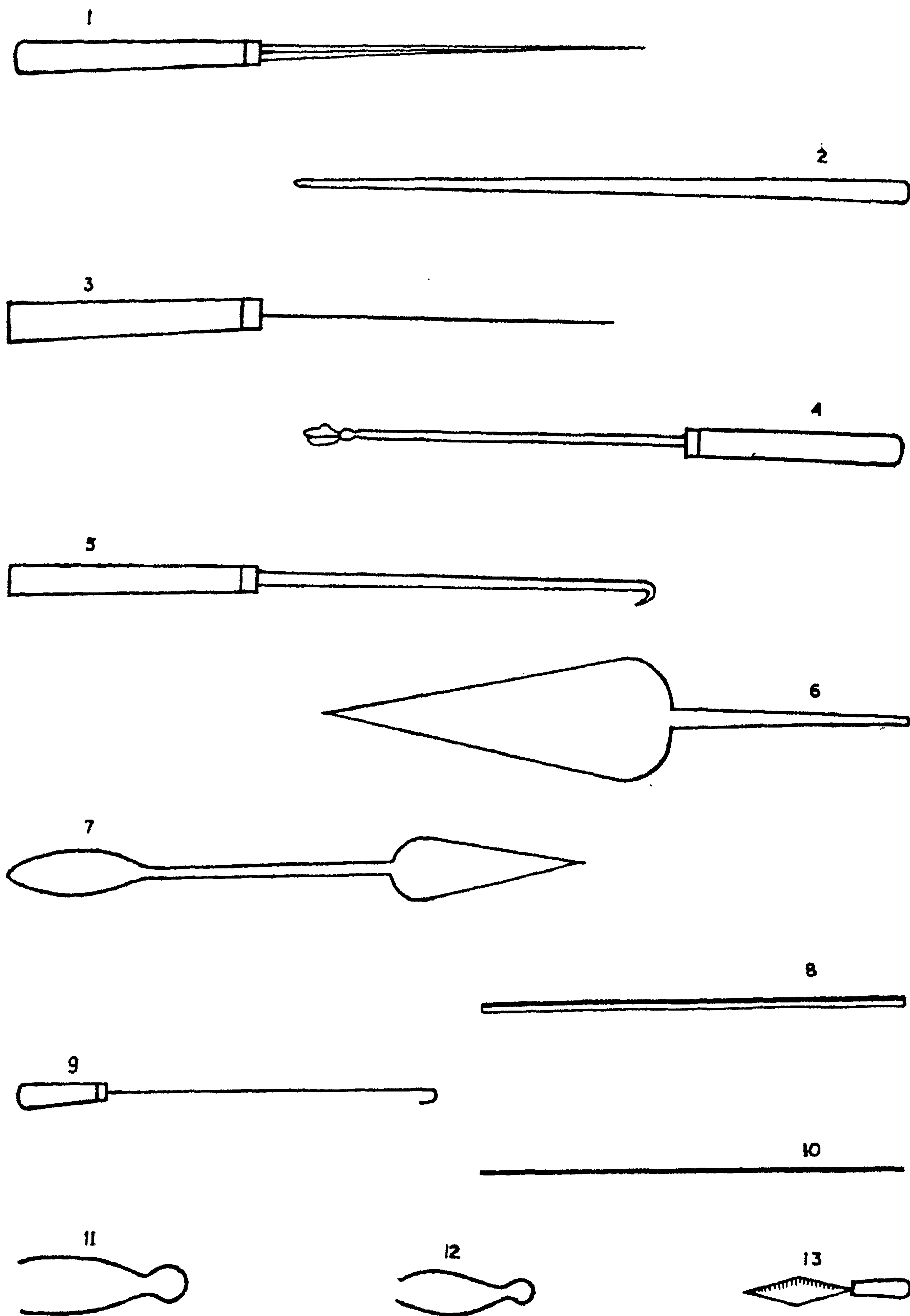


Fig. 11. Glass Making Tools used by Traditional Glass craftsmen. 1. Sargañjana 2. Sarañga 3. Bardhana 4. Kalcul 5. Añkarī 6. Patha 7. Kalbut 8. Nat 9. Añkari 10. Sarendi 11.and 12. Massa 13. Mallah (Courtesy: H.G.Dikshit, 'History of Glass')

III. *Aṅkari*: A long iron rod (about 2 feet in length) hooked at one end and fitted with a wooden handle at the other. It was used for stirring of molten glass and dishing it out.

IV. *Patha, Thapi, Mallah*: It is a dagger or trowel shaped tool, used for pressing and moulding glass in molten state.

V. *Kalbut*: This is a clay cone, fixed to a wooden handle, It is used for enlarging glass bangles to requisite size.

VI. *Nal, Phuṅkni*: It is a blow pipe, about 2 feet in length used for blowing glass.

VII. *Massa*: Iron shears, these were used for shaping objects and separating glass from the blow pipe.

VIII. *Cimṭā*: Flat iron tongs used for handling broken chips of glass in the furnace.

IX. *Sīl*: A slab of stone corresponding to marver. It was used for rolling ends of glass on the blow pipe.

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Gems and Minerals

ARUN KUMAR BISWAS

The crustal layer of this earth, constituting of rocks and minerals, has provided the basic resources for the material civilization. The only other important substratum has been the vegetable kingdom which depends upon the mineral constituents of the soil. Minerals have been used directly as gems, pigments, and to prepare metals as well as brick, mordant, pottery, glass etc.

This paper deals with certain aspects of the 'gem-minerals' and 'non-gem minerals' in ancient India and devoted to the following sub-topics:

A. the nature of evidences that we have on the subject.

B. a brief narrative on minerals and gems from Mehargarh to Taxila.

C. specific discussions on some selected gem-minerals and non-gem minerals in ancient India.

D. specific discussions on some selected metalliferrous ores in ancient India.

E. the need for further studies and research on the subject.

A. The Nature of Evidences

There are several kinds of evidences regarding the production fabrication and uses of gems and minerals in ancient India:

(i) ***Archaeological Excavations***: This is an on-going tradition of research unearthing material traces of old civilizations. The pre-Harappan sites like Mehargarh, the Harappan, post-Harappan and the Historical period sites have shown a bewildering variety of gems, minerals, artifacts and metals, derived from specific minerals, and also many archaeomaterials. A central issue is whether some of the materials were imported from outside the international borders or fabricated out of ores and minerals mined from the Indian subcontinent. The question of ore-artifact correlation has been widely debated and would be briefly examined in this paper.

(ii) ***Evidences of Industrial Activities***: A special feature of some of the excavated sites is the existence of industrial sectors related to manufacture of beads, metals

etc., showing furnaces and residual slags and waste products. These confirm the nature of indigenous activities.

(iii) ***Mining Archaeology***: This is a new field of research in India. While there are many which are believed to be 'ancient', the dates of their excavations are not established in all cases. We report in *Table 1*, a gist of the important C-14 dates of some of the ancient mines. The earliest date (of 1260 B.C.) reported so far corresponds to Ṛajpura-Dariba of Rajasthan. Mining in ancient India has been reported in detail elsewhere (Singh, R.D.)

(iv) ***Literary Evidences***:Spanning from *Ṛgveda* to *Rasaratnasamuccaya* we have a huge amount of Sanskrit literature corresponding to a period of two to three millennia, which contains many details regarding our subject. There are also Pali, Greek, Roman and Arab literatures describing the widespread uses of gems and minerals in ancient India.

We have prepared a comprehensive report on minerals and metals in ancient India and submitted the same to the Indian National Science Academy (Biswas, A.K., 1991). Our treatment here contains only a very small segment of the above report. The details of ancient mining and metallurgy in India are covered elsewhere in this book by Singh, Agrawal and Prakash. This paper seeks to fill certain gaps between mining and metallurgy, and is devoted to the raw material aspects rather than fabrications (lapidary) or smelting (to metals).

B. Mehargarh To Taxila

We would now briefly review in this section the minerals and gems found in the successive periods from pre-Harappan Mehargarh to Taxila around the onset of the Christian era.

Table 2 listing some material artifacts found in the successive phases of Mehargarh in Baluchistan prove that a large number of materials in the pre-Harappan and mature Harappan cultures were of indigenous origin. A large variety of stone tools were produced during the 7th-4th millennium B.C. period not only in the Mehargarh area but also in the Ganga-Vindhya complex and Bagor area in Rajasthan. Blades and burins of flint, quartzite basalt, dyke basalt, chalcedony, obsidian, jasper, chert etc. were produced in large scale around Mehargarh, Kile Gul Mohammad, Damb Sadaat, Balakot etc.

Alabaster or gypsum bowls used to be made using tabular drill at Damb Sadaat and Mundigak. Around 5000 B.C. there was a workshop for soapstone beads at Mehargarh. Shell bangles, rings, beads and pendants used to be made in the pre-Harappan sites from the Indian variety of *Śaṅkha* (*Turbinella pyrum Linn*). Hornell (1918) and Mackay (in Marshall, 1931, II: 564-66) have described how the walls or the hollow tubular piece could be sawed for producing bangles and the inner columella for making beads and inlays. Chisel or burin, saw and drill were used to produce diverse objects. The remarkable work of Dales (1977 & 1979) has shown shell beads in Balakot (located near the sea-coast), Period I and working floors in Period II covered with large quantities of shell bangles in all stages of manufacture. The appearance of faience suggests the early use of *sājji māṭṭi* -like effervescence deposits of the soil containing sodium salts.

Table 1 — Some C^{14} Dates Related to Metallic Ore Mines in Ancient India (Half Life of C^{14} 5730 years)

Date	Site	Comments	Source
1260±160 B.C.	Rajpura-Dariba, Udaipur, Rajasthan	Sample PRL-208 (b)	Chakrabarti (1986: 194)
1130 B.C	-do- South Lode	Silver-rich Pb-ore main. Target around 100 m.depth also nearby Zn-Cu ore	Willies (1987:90)
1050±150 B.C.	-do-	South Lode 100 m. timber support. Sample *Aogeissus sp* examined at NPL, Ahmedabad	Paliwal *et al*
760±15 B.C.	Hatti, Karnataka	Gold field sample PRL-253	Chakrabarti (1986:194)
375±85 B.C.	Bamboo sample dated by Teledyne Isotope	U.S.A. East Lode 263m. timber support. Pb/Ag Ore; also Cu-Zn	Paliwal *et al*
360±105 B.C.	-do-	TF - 1117 sample; copper working depth 64 m, layer 436	Agrawal and Kusumgar (1975)
250±100 B.C.	-do-	PRL-208 (a) East Lode, 4-5 m. *Acacia sp* wood sample. Extensive timber work on the east side for a length of 150m. extending south-east corner	Chakrabarti (1986:194) PRL C-14 date list, Paliwal et al, Willies (1987:92)
120 B.C.±280	Rajpura-Dariba	South Lode 100 m. depth, rope. Dated by Teledyne	Paliwal *et al*
150 A.D.	Rajpur-Dariba	East lode 254 m. depth	Willies (1987:90; 1989:32)
110±130 A.D.	-do-	PRL-210	Chakrabarti (1986: 194)
370 B.C.	Rampura-Agucha	Pb-Zn mine. Primary target was argentiferous galena.	Willies (1987:92)
250±60 B.C.	-do-	*Terminalia sp* wood support from 30 m depth. BM 2356 sample	Paliwal *et al*
430±100 B.C. Zawarmala, Rajasthan	PRL 932 sample.	Zn-Pb ore mining	-do-

Contd.

(Contd. Table 1)

Date	Site	Comments	Source
380±50 B.C. Mochia mine, Zawar	*Terminalia sp* sample BM 2381 Zn-Pb ore mining	-do-	
170 B.C.	Zawarmala	a sample from a set of steps	Willies (1987:84)
200 and 140 B.C.	-do-	'Timber chamber' and burnt wood in 'Main Chamber' samples	Willies (1987:86)140±60 B.C.
60±50 A.D.	-do-	Timber from Launder BM 2149	-do-
1750± 60 A.D.	-do-	Zinc smelting site, charcoal, BM 2223	-do-
1810± 50 A.D.	-do-	Balaria mine timber BM 2338	-do-
140 ± 200 B.C.	Ambamata, Banaskantha, Gujarat	12 m. distance in No.3 West Drive.65 m. depth PRL-53. Copper-Lead-Zinc ore	Agrawal et al (1976: 135) Shekar(1983:178)
1130±100 A.D.	-do-	Wood sample from bore-hole A-100.	PRL-66
30±70 A.D.	Hatti, Karnataka	Site no.1. Gold ore	Agrawal *et al* (1975-76:139)
110±70 A.D.	-do-	Site no.2. Gold ore	-do-
170±35 A.D.	Ingaldahal, Karnataka	Copper mine 30-40 m.depth. Wood sample BM 2364	Paliwal *et al*
220±110 A.D.	-do-	PRL-252	Chakrabarti (1986:194)
475±115 A.D.	Kolar, Karnataka	Sample TF 879. Champion reef 50 m. depth, Gold ore.	Agrawal *et al* (1975- 76:139)
685±90 A.D.	-do-	Sample TF 1199. Superficial excavations. Gold ore	-do-
1070±80 A.D.	Bandlomattu Hill, Guntur, Andhra Pradesh	TF 805. Copper ore	Agrawal *et al* (1976: 135)
1320 A.D.	Bandlomattu Hill, Guntur, Andhra Pradesh	TF 806 Copper ore	Agrawal *et al* (1976: 135)

Contd.

(Contd. Table 1)

Date	Site	Comments	Source
1070±85 A.D.	Kumbaria, Banaskantha, Gujarat	Dumps behind Jain temple TF 1222 Charcoal (A C-14)	Agrawal *et al* (1976: 135)
1440±90 A.D.	-do-	TF-1221 Charcoal (A C-3)	-do-
1440±90 A.D.	Mailaram, Khammam, A.P.	TF 373. From a slag heap 1 m. depth. Copper metal	-do-
1640±80 A.D.	Kaladgi, Hassan, Karnataka	PRL-254. Copper mine	

In the Mature Harappan Phase, certain gem minerals like lapis lazuli and turquoise might have been imported to Mohenjo-daro from Iran. But the bulk of limestone, gypsum, alabaster etc. came from the local sources. Steatite was not only locally available but also indigenously processed from the manufacture of beads and seals. Nepheline-sodalite rock and yellow stone of Jaisalmer came from Rajasthan.

Table 2 — Materials in Mehargarh Phases (Jarrige, 1979 & 1984)

Period	Dates (millennium B.C.)	Materials
I a-c	7^{th}-6^{th}	Flint tools; grinding stones; cakes of red ochre, beads and belts of shell, turquoise, lapis lazuli, cylindrical copper bead
II	6^{th}-5^{th}	Soapstone beads, flint drills, *waste* flakes indicating local manufacture, red ochre, copper ring
III	1st half 4^{th}	Green cylindrical jasper drills and micro- drills for lapis lazuli, turquoise and carnelian some adhering melted copper
IV	Middle 4^{th}	Wheel-thrown pottery
V	End 4^{th}	White pigment
VI	Beginning 3^{rd}	Mass production of pottery and terracotta. Pottery kiln. Red ware. Spiral bronze pin
VII	Middle 3^{rd}	Beads of kaolin, carnelian and lapis lazuli. Alabaster ram. Bronze items.

Excavation in the DK area of section G in Mohenjo-daro conclusively proves that copper and bronze items and castings were manufactured from the Indian ores such as oxide and sulphide ores of copper, lollingite (containing arsenic etc.). Argentiferrous lead ore and alluvial washings of tin ore (cassiterite) also must have been processed.

Two special items found at Harappa are coral and mica. Coral was not at all noticed at Mohenjo-daro where micaceous clay was used but no mica as a separate piece was found as in Harappa. The yellowish limestone, grey granite and basalt were to some extent special in Harappa.

Bead Industry of Chanhu-daro

The Chanhu-daro Harappan site showed not only metals such as copper and bronze but also the manufacture of a wide variety of mineral and gem-beads. Different types of beads have been unearthed from Chanhu-daro in course of excavation. Among the numerous specimens, many were found unfinished, broken in boring or rejected on account of bad colour and the like, thus proving these were locally made and not imported.

Agate and carnelian were the materials most generally used in the manufacture of beads during this period, carnelian being decidedly the rarer. Somewhat less common were faience, vitreous paste, steatite and products made out of it. Beads made of other materials were copper or bronze, shell, lapis-lazuli, jasper, a variety of hornblend, crystal, quartz, Amazon stone, chalcedony, limestone, onyx, fuchsite-quartzite, haematite, breccia, plasma; no amethyst bead was found. Thus, it is proven from all the beads discovered at Chanhu-daro, that the site was undoubtedly a great bead-making centre. Most of these beads came from the quarters of the craftsmen who made them, not only for themselves but also for distant cities.

On a broader perspective, Horace Beck (1933 & 1941) placed the Indus beads under the following three headings: I. White on red, the most common type, I. Black on a white coloured base, III. Black on a red ground. Among these, only two types i.e. I and II have come to light at Chanhu-daro.

The patterns of the *Type I* beads were made by using as paint a coat of alkali, such as carbonate of soda and then fixing it by heat. The paint is left with a glossy white surface and adheres to the stone so firmly that it is almost impossible to remove it by simple means. The technique is still carried on in Persia, on the borders of China and sporadically in Sindh. In the last province, the juice of a plant is mixed with alkali, presumably to keep it from flaking off the stone before it has been made fast by heat.

It is uncertain what medium was used to produce the black coloured patterns on the type II beads. The white back-ground was formed by flooding the red carnelian with the alkali, thus creating a white opaque surface. According to Horace Beck it is also possible that a copper solution was used as the paint. Thus to apply fine and even lines and firing on the beads, the greatest skill must have been required.

Two unfinished beads of lapis lazuli prove that this stone was actually worked upon at Chanhu-daro; the finished specimens are not therefore likely to be importations. The source of this mineral is thought to be Badakshan, while new provenances for amazonite is to be found in the pegmatites near Jhajha (Monghyr Dist., Bihar), the Nellore district, Madras and Ahmedabad.

The two beads of fuchsite-quartzite are particularly interesting, because this rare mineral was never used at Mohenjo- daro. A large cup, carved in almost pure fuchsite was found there, together with a collection of copper and bronze tools and other objects. The colour of this stone is light green and its source is most probably Mysore.

Four wafer-shaped mother-of-pearl beads were unearthed from Chanhu-daro. Beads of this particular substance are very rare at Mohenjo-daro. Jade does not seem to have been used at Chanhu- daro, and this statement also applies to various other stones that were used for bead at Mohenjo-daro. A large number of nodules of carnelian and agate were discovered from Chanhu-daro - the former being as a rule easily distinguishable from the latter by the darkness of its skin.

The carnelian beads were made from roughly flaked stone blanks averaging 0.58 inch in diameter and 0.21 inch thick. Each of these beads has been bored with a chert drill. All the holes were splintered rather than cut, and were necessarily smoothed down and polished later. Before this was done however, the heads were shaped by grinding. A number of these were probably stung on a thread, or more likely on a piece of copper wire, and then rolled to and fro on grit-stones of various grades, each bead being allowed sufficient play for its rounded edge to be properly formed.

The agate beads had first been severed from the parent nodule by sawing and then by splitting. The shaping of barrel-cylinder type was carried out entirely by careful flaking. When all depressions and irregularities had been smoothed away by grinding, the object was then polished. Before this final finish took place, the bead had to be bored, a process that was carried out from both ends by means of drill.

Quite significantly, broken drills were found everywhere in Mound II and though these might have served again in the boring of the shorter hardstone beads, it is obvious that the drill- makers, if indeed the bead-makers did not manufacture their own tools, must have been hard put to supply the demand. Though unfinished beads of hard stones have been found on many Sumerian sites, only one stone drill has been found in that country. This was identified by Beck among some objects from Ur. Thus Mackay comments "indeed it is not at all unlikely that bead-making in Sumer was carried on by Indian craftsmen".

The segmented beads have appeared over such a wide area in India, that it is quite impossible to say where the type originated. Indeed such a simple form of bead need not have had a particular region of origin at all. At Chanhu-daro as well as Mohenjo-daro, such beads were produced by a kind of mass production. These were made in long rods which after glazing were to be divided into segments of uniform length. The rods found at Chanhu-daro were too long and too delicate to have been used for any other purpose than to be broken into convenient lengths.

Steatite Beads

Small blocks of steatite in light yellow, dark-grey and black were not uncommon in various parts of Mound II. Many of them bear the marks of the saw which had cut them up into shapes suitable for both beads and seals. Pieces that could not be used for any other purpose were ground into powder and then compressed into blocks, from which beads and even occasionally seals were made. This made-up steatite is always white in colour and was probably calcined before compression. It is often very difficult to detect the difference, especially as objects composed of it are more often than not coated with a glaze.

Although Hoarce Beck was not disposed to agree that reformed steatite was used by the people of the Harappa culture, F.A. Bannister of the Mineral Department of

British Museum reported that steatite paste would become indistinguishable from the natural material after being subjected to a very high temperature. In ancient India, the steatite beads were sometimes heated to a temperature exceeding 1200°C, and it has been proved that (the heap of) minute beads were treated to this degree of heat. These must have been composed of a paste which could be forced thorough fine tubular instruments.

Among all the beads found from Chanhu-daro, the pile of minute steatite beads was an exceptional find. The manner in which these beads lay in lines on the pile proved that these were originally strung together. F.A. Bannister and G.F. Claringbull of the Mineral Department of the British Museum who examined some of these beads, reported that the beads are small hollow cylinders which vary in external diameter 1/2 (.019 inch) to 1 mm and in length from 1/2 to $1^1/_2$ mm. When freed from loosely adherent soil, they are pure white and very hard. Nearly every bead is furrowed along its length spirally, always in a clock- wise direction. It is not uncommon to find two beads joined together with the spiral furrowing running continuously and in perfect alignment from one to the other. The physical and chemical data are conclusive about the material from which these beads were made. Their specific gravity is 2.85 and the refractive index of crushed fragments is 1.60. The beads can be fused only in the electric arc, and then yield glassy spheres with a lower specific gravity 2.72. Except magnesium and silicon no other element could be detected with the quartz spectrograph. X-ray powder photographs show that the beads are steatite that has been completely dehydrated and heated to a temperature exceeding 1200°C.

Recently, Hegde et al (1982) have examined the Harappan microbeads made of steatite and obtained from Zekda, located in Banaskantha district in the northern part of the Gujarat State. The raw material was aluminium-containing talcose steatite available in Ambaji near Zekda. The X-ray diffraction patterns in the finished beads revealed the presence of silica in the form of cristobalite and anhydrous magnesium silicate in the form of enstatite. When talc is heated around 900°C it loses its water of crystallisation, forms cristobalite and enstatite, and improves its hardness from one to seven on the Moh scale.

The Harappans used steatite, a soft stone for making seals and beads and then hardened the same. A paste of finely ground talcose steatite was squeezed through one millimeter diameter perforations having 0.5 mm diameter copper of bronze wires in the centre of the perforations to produce hollow tubes which were cut into small bits and then hardened by firing at 900°C. According to Hedge et al, this was the method of production of steatite beads.

The majority of the beads found at Chanhu-daro were unfinished, broken in boring which proves that these were actually made at Chanhu-daro. This inference has been corroborated by the discovery of the bead factory with furnace here. To the north-west corner of the main street of the Mound II was a remarkable building with several furnaces; this evidently housed the bead factory amongst other fabrication facilities.

Some Lothal Products

At Lothal, manufacture of steatite beads and seals was as impressive as in Chanhu-daro. Special features at Lothal were however pertaining to agate, carnelian and shell (Rao, S.R., 1979 & 1985).

Among the semi-precious stones, carnelian was the most popular, not only because of its attractive red colour and translucency but also on account of the easy availability of agate (from Rajpipla conglomerate, Rangpur etc.) which was cooked to produce different shades of red, yellow and lemon carnelian/sard. These are all crypto-crystalline silica belonging to the chalcedony family of minerals. The colour of red carnelian is due to ferric oxide disseminated in the silica matrix, and the yellow and brown to hydrated ferric oxide.

Yellow or brown stones, when exposed to the action of heat, gradually assume the red colour (characteristic of carnelian) owing to the hydrated ferric oxide losing water and becoming anhydrous.

The Block E of Lothal showed bead factory, furnaces and more than 600 beads of carnelian in different stages of manufacture. Its primacy for the tradition of etched carnelian beads is unquestionable.

Various types of marine, estuarine and fresh water shells - particularly *chank* Xancus (Turbinella; pyrum linn.) - were used at Lothal in the manufacture of precision instruments, ladles, engravers, knives, inlay pieces, gamesmen, personal ornaments such as beads, bangles and pendants, and occasionally for seals.

While the dock collections at Lothal included both marine and fresh-water species of shells, the township collections specifically abounded in *chank* amongst other things. Hundreds of columella of chank-shell, rejected flakes, unfinished bangles and other finished objects of shell, found in the workshops of Lothal, confirm that shell-working was a flourishing local industry. One of the workshops encountered in street 1 was devoted to shell-bead industry.

The process of sawing, engraving and giving final shape to the shell objects was almost identical in Kathiawar and the Indus Valley. The saw marks on the columella and the valva clearly show that the shell was turned slowly while sawing with a bronze wire.

The thick rings produced from the septum were sawn into thinner pieces for making bangles. The walls of the chank-shell were made use of in preparing bowls and ladles (1.4 to 4.6 in. diameter).

A very interesting instrument made of shell is a hollow cylindrical object with symmetrical loop-like curves, produced at regular intervals by partially sawing across the opposite margins. Four grooves on the upper margins of the cylinder and four on the lower when joined, give intersecting lines producing exactly 45 degrees. The instrument must have served the same purpose as a modern compass and helped in marine and land survey, alignment of road etc. Another leaf-shaped object with a semi- circular end might have been used as a plectrum for playing on a stringed instrument.

Mention may also be made of the use of bones and ivory at Lothal. There was trade of ivory between India and Sumer. Ivory was used for making kohl rods,

gamesmen, jar-stoppers, ceremonial knives, and most interestingly, scales upto 46 mm distance with the smallest division being 1.7 mm.

Agate and carnelian continued to be the principal gem minerals for making beads during the Historical Period. Out of the sixty beads of semi-precious stones recovered from the IV^{th} phase (post 600 B.C. period) of Atranjikhera in Western Uttar Pradesh, 25 were agate beads, 15 carnelian, 10 jasper and 8 quartz (Gaur, R.C., 1983). At Hastinapura, 211 beads were found in successive phases starting from 1000 B.C.; 78 were made of carnelian and agate (Lal, B.B., 1954 & 1955). At Ahichchhatra (post 300 B.C.) a large majority of the stone beads were made of banded and etched agate and carnelian (Dikshit, 1952).

Three principal types of etching, as discussed earlier, were noticed on carnelian beads (Dikshit, 1952). The long-barrel circular beads and leech-shaped beads were found not only at Ahichchhatra but also at Kaushambi, Taxila etc. The beads must have had common origin of manufacture; etched agate and carnelian possibly came from the Cambay area.

The Beads at Taxila

The beads recovered at Taxila number over 8500, a quarter of the number from the Bhir Mound, 65 p.c. from Sirkap and the rest from Dharmarajika and other sites (Marshall, 1951, 1975). A stratigraphical table of beads from Sirkap, Taxila is provided in *Table 3*. The inhabitants of the Bhir Mound area preferred agate, carnelian, shell, bone and glass - blue and green. In the later- day Sirkap inhabitation, we find continued uses of agate and carnelian and considerable uses of shell, glass, faience, quartz crystal, garnet, malachite etc. (vide Table 3).

The etched carnelian beads belonged to all the three varieties as described by Beck (1933 & 1941): (a) etched in white by sodium carbonate or other alkali solutions, (b) etched in black by copper or iron nitrate on the white background or (c) on the natural colour. This confirms the continuity of the tradition of etched beads in India.

Glazed quartz beads, found even in the Bhir Mound, became more popular during the first century A.D. Saka-Parthian period. The process of glazing consisted in heating the bead with soda until the quartz fused and flowed as a glaze over the surface.

Spectroscopic examination made by Beck (1933) showed that the surface of the beads, thus treated, contained a large quantity of soda, though the interior was free from it. Some reagent must have been used to provide pale blue colour to the beads. Natural quartz is more beautiful when polished than when glazed; therefore, the only purpose of glazing was to provide colour on the molten surface.

Marshall's view (1975: Chapter 37, p. 739) is "that the real purpose of glazing was to give to quartz the appearance of beryl or aquamarine, both of which were very rare and very much prized. Pale blue would give to quartz an appearance like that of beryl or aquamarine, and this no doubt is why one of these beads from Sirkap was cut to the shape of a hexagonal cylinder, which is the natural form of beryl".

Pliny (N.H. 37.20) wrote that the lapidaries cut all beryls to a hexagonal from, because the colour is heightened by the reflection from the angles. Apparently, he

Table 3 — Stratigraphical Table of Beads from Sirkap, Taxila (Taken from Marshall, Chapter 37, p. 734). (Not including the gold and silver specimens)

Material	Pre-Greek	Greek	Early Saka	Saka Parthian	Surface	Total
Semi-precious stones :						
Agate	-	1	10	111	3	125
Amethyst	-	1	-	10	1	12
Aquamarine	-	-	2	1	-	3
Beryl	-	-	-	2	-	2
Carnelian	1	3	21	215	11	251
Carnelian, etched	-	1	-	8	-	9
Chalcedony	-	1	2	2	-	5
Garnet	-	-	3	24	2	29
Jasper	-	2	2	20	2	26
Lapis-lazuli	-	1	3	28	2	34
Malachite	-	-	7	40	2	49
Onyx	-	-	1	2	-	3
Quartz crystal, colourless	-	1	2	46	2	51
Quartz crystal. yellow	-	-	-	4	-	4
Quartz crystal, glazed	-	1	2	39	1	43
Quartz crystal, opaque	-	-	-	2	1	3
Turquoise	-	-	-	1	-	1
Blue serpentine	-	-	-	5	-	5
Red serpentine	-	-	-	1	-	1
	1	12	55	561	27	656
Common stones:						
Granite	-	-	-	3	2	5
Limestone, white	-	-	-	1	-	1
Limestone, nummulitic	-	-	-	3	-	3
Marble	-	-	-	2	-	2
Steatite(soapstone)	-	-	2	7	-	9
Shale	-	-	1	1	-	2
Nondescript	-	-	2	11	-	13
			5	28	2	35

Contd.

(Contd. Table 3)

Material	Pre-Greek	Greek	Early Saka	Saka Parthian	Surface	Total
Metals (excepting gold and silver):						
Copper	-	1	2	4	2	9
Miscellaneous						
Amber	-	-	-	7	-	7
Coral	-	2	-	2	-	4
Shell	1	16	224	1,144	58	1443
Bone.	-	-	-	11	2	13
Faience	-	13	7	198	4	222
Ebony	-	-	-	2	-	2
Ebonite	-	-	-	1	-	1
Jet	-	-	-	3	1	4
	1	31	231	1,368	65	1696
Glass						
Ambe	-	-	2	56	1	59
Black	-	1	-	17	2	20
Blue.	-	8	27	203	9	247
Cobalt blue	-	-	-	1	-	1
Pale blue	-	-	2			2
Peacock blue	-	-	-	1	-	1
Cream-coloured	-	-	-	3	-	3
Green	1	-	10	336	5	352
Grey	-	-	-	68	-	68
Orange opaque	-	-	-	139	-	139
Red	-	1	-	5	-	6
Violet	-	-	-	1	-	1
White opaque	-	-	-	22	1	23
Yellow	-	-	-	4	-	4
Yellow opaque	-	6	182	1,437	1670	
Blotched	-	-	1	2	-	3
Multi-coloured and colourless	1	9	31	474	18	533
	2	25	255	2,769	81	3132
Terra-cotta	-	-	1	4	1	6
Total	4	69	549	4,734	178	5,534

was unaware that the hexahedral was the natural form of beryl. Beryls came mainly from the Coimbatore district of Madras. Pliny also made a very significant statement: "The people of India, by colouring crystal, have found a method of imitating various precious stones, beryls in particular".

Intermediate in properties between glazed quartz and fused glass is faience, which is made by breaking up quartz into small grains, adding a small amount of lime, and fusing until the surface of the quartz has flowed and cemented the whole into a solid mass. The quality of the faience depends upon the fineness of the grains and the degree of fusing. Mohenjo-daro and Harappa produced some unusually fine-grained and hard faience, but most of the samples were coarser and more friable. This commoner variety was locally produced in Taxila for making beads during the later Saka-Parthian period. Compared to the Bhir Mound collection, the Sirkap collection showed much larger faience, glass and shell beads. Whereas in the former collection, the percentages of the beads made of semi-precious stone, glass and shell were 42, 32 and 14 respectively, the corresponding percentages in the later-day Sirkap became 12, 50 and 26 respectively. The figures show the spurt of artificial gem industry, mentioned in the drama *Mṛcchakaṭika.*

C. Some Selected Gem Minerals

The gem categories of importance in the ancient world are listed in *Table 4*. The Sanskrit names confirm the ancient uses of the gem-minerals in India. Actually the etymological origin of many English names was Sankskritic e.g. 'Kuruvinda' gave rise to 'Corundum'. Since many minerals acquired similar colours on account of impurities, hardness values, as listed in *Table 4*, were of great importance in identification. Coloured glasses were often used to imitate gems and therefore the ancient gemmologists checked hardness to distinguish between true and fake gems.

Gem Minerals Containing Beryllium

We would now discuss the family of gem minerals containing beryllium, variously coloured, specially green and blue, and having similar hardness. In terms of chemical composition, a sharp distinction has to be made between chrysoberyl (hardness $8^1/_2$) $BeAl_2O_4$, a mixed oxide, and beryl (hardness $7^3/_4$) $Be_3Al_2Si_6O_{18}$ a cyclo-silicate. The difference in their hardness could be easily tested using another gem, topaz having an intermediate hardness of eight. In absolutely pure form, both chrysoberyl and beryl are colourless. Their colours in the gem form arise on account of lattice substitutions by other elements as specified in *Table 4.*

Due to chromium and iron, chrysoberyl samples assume green and yellow colour respectively, the more usual green colour often merging into golden yellow. Milky white or greenish white cloudy chrysoberyl samples (not the clear and transparent ones) exhibit chatoyancy. Extending across the curved surface of such stones is a silvery line or streak of light, when viewed in a strong light. These samples are called chrysoberyl or oriental cat's eye. The phenomenon of chatoyancy is due to the existence in immense numbers of microscopically small cavities arranged in a particular direction or a bundle of microscopic channels running parallel to a single direction. When viewed at right angles to this direction, a band of light is visible

Table 4 — Gem Categories Of Importance In The Ancient World

Name English/Sanskrit	Colour	Hardness (Moh's Scale)	Reasons for non-white colour
Diamond/*Vajra*	usually colourless	10	Blue due to boron, yellow/green due to nitrogen
Corundum/*Kuruvinda*	"	9	Pure Al_2O_3 is colourless
Ruby *Padmarāga*	red	9	Cr^{3+} replaces Al^{3+}. Transition involving ligand field effect
Sapphire *Indranīla*	blue	9	Four different mechanisms including charge transfer, combination of Fe and Ti
Non-blue *Sapphire*		9	Orange
Chrysoberyl/Cat's eye *Marjaraksaka/Lasunia*	Green/Yellow	$8^1/2$	Green due to Cr and yellow due to Fe substituting in Be Al_2O_4 structure.
Spinel/Balas-ruby/ *Bālasūryaka*	rose-red	8	Pure spinel Mg Al_2O_4 is colourless. Cr^{3+} substitution makes it rose-red. Fe and Mg may further alter the colour.
Topaz/*Pusparāga*	Yellow	8	Pure topaz is colourless [Al (F,OH)]2 SiO_4. Yellow colour is due to impurities - ferrous oxide lime and alkali. Dichromic also blue
Beryl/*Vaidūrya*	Faint green water colour	$7^3/4$	Pure beryl Be3 Al_2 Si_6O_{18} is colourless. Faint green due to substituting Cr^{3+}. This is allochromatic effect - transition involving ligand field.
Emerald/*Marakata Pānnā*	Deep grass green	$7^3/4$	This is beryl containing more Cr^{3+} imparting green colour. Dichroic, the second blueish colour is due to iron.
Aquamarine/*Pāribhadra*	Faint blue to bluish green	$7^3/4$	Bluish tinge due to iron

Contd.

(Contd.Table 4)

Name English/Sanskrit	Colour	Hardness (Moh's Scale)	Reasons for non-white colour
Zircon/*Gomed*	Cow-flesh colour	$7^1/_2$	Pure zircon $ZrSiO_4$ is colourless. Reddish-yellow colour of Hyacinth is due to Fe^{3+} decolourised on reduction to Fe^{2+}
Garnet/*Tāmrya* or *Tāmḍi*	Various colours	$7^1/_4$	Family of minerals $M^{2+}{}_3$ $M^{3+}{}_2$. $(SiO_4)_3$. Colour depends upon chemical composition. Hessonite is confused with Hyacinth. Colour due to iron.
Tourmaline/*Vaikrāntā*	Various colours	$7^1/_4$	H_9 Al_3 $(B.OH)_2$ Si_4O_{19} pure tourmaline is light coloured. Fe^{2+} and Cr^{3+} make it dark green, Mg makes it brown and Mn dark red.
Quartz/*Sphaṭika*	Colourless	7	Pure SiO_2 is colourless. Yellow citrine due to iron green chrysoprase due to nickel, violet amethyst due to manganese etc.
Agate/*Akik*	Light colour	$6^1/_2$	Hydrated SiO_2 is colourless Hydrated ferric oxide as impurity makes it brown or yellow.
Carnelian/*Rudhirakhya*	Red		Heating causes dehydration and ferric oxide gives red colour to carnelian.
Olivine/Chrysolite/Peridot *Puttika/Jabarjad*	Bottle green	$6^1/_2$	Pure Mg_2SiO_4 is colourless Replacement of part of MgO by ferrous oxide makes it yellowish green. Mn^{2+},,Ni^{2+} further change the colour.
Orthoclase/Feldspar Moonstone/*Candrakāntā* Sunstone/*Sūryākantā*	Opalescent play of colour	6	Interference of light from thin layers.
Jade/*Pīlu*	White green black	$5^1/_2$ - 7	Green due to Mn and Cr and Fe^{2+}. Black due to Fe^{3+}

Contd.

(Contd. Table 4)

Name English/Sanskrit	Colour	Hardness (Moh's Scale)	Reasons for non-white colour
Turquoise	Blue		The mineral is derivative for ortho- phosphoric acid, the hydrogen atoms replaced by radicals such as $Al(OH)_2$ $Fe(OH)_2$ (providing green tinge) and Cu(OH), providing intense blue colour.
Lapis Lazuli/Ultra-marine/ *Rajāvārta*/ *Lajhward*	Deep azure blue	$5^1/_2$	The constituent minerals are Sodium-Calcium-Aluminium silicates with sulphate and polysulphide (S^-_3) anions. The 19 outer electrons of S^-_3 unit undergo transitions within the molecular orbitals. These produce absorption band in the yellow range and hence intense blue colour. Less sulphur in the mineral system gives green colour which makes the gem less worthy.
Pearl/*Mukta*	Usually white	3-4	Iron, manganese etc.possibly complexed with organic matter, so that the colour is perishable on heat.
Coral/*Pravāla*/*Vidruma*	red.black etc.	3-4	"

running across this bundle. The stone is usually cut along this direction so that maximum number of light-reflecting cavities are close to or on the surface, producing maximum chatoyancy. Quartz cat's eye samples (hardness 7) show similar chatoyancy or a wave of milky light reflected from the surface, the effect in this case arising due to the presence of large number of fibres of asbestos aligned in a specific direction.

Beryl, *vaidūrya* in Sanskrit, has a hardness ($7^3/_4$) different from those of chrysoberyl ($8^1/_2$) and quartz (7), and the modern literature does not indicate that chatoyancy is observed in any beryl sample. However, green chrysoberyl sometimes looks like green beryl, and since the former gem exhibits chatoyancy effect occasionally, the Indian word *vaidūrya* has in some instances been used

(unfortunately) to indicate cat's eye gem also. Buddhabhaṭṭa's writing (Ratnaparikṣā or RP 200) created this confusion for the first time.

Pāṇini referred to *vaidūrya* coming from Vidura. Later Patañjali, the commentator of *Aṣṭādhyāyī*, explained that the gem actually came from the Valavaya mountains, and was only processed in the town of Vidūra (which must have been located somewhere in South India). Centuries later, Buddhabhaṭṭa wrote about Kongavalikasimanta near the Vidūra mountain as the source of beryl or Vaidūrya (RP 199).

Sarma (1984: 68) opined that the etymological link between Vidura and vaidūrya was 'a fiction invented by the grammarians', but we do not agree with him, since Patañjali's explanation and Buddhabhaṭṭa's corroboration have been clear enough; Patañjali's *Valavaya* (mountain) is similar to Buddhabhaṭṭa's *Valikā*. It is well-known that Konga kingdom once governed the beryl mine of Coimbatore of the Salem district from which beryl gems were supplied to the Romans.

Alfred Master has suggested (1943-46) that the *veluriya*, the Pali word, was actually a Dravidian word preceding Pāṇini's *vaidūrya*, and both were the adjectival forms of *Velur* (or modern Belur), which is in the heart of the beryl mines of Coimbatore. The 500 A.D. inscription of the Ganga king Durvinita mentions both Velur as well as the Punnata kingdom described by Ptolemy as 'Punnata in which is the beryl'. Velur might have been known to Panini as Vidur ('the far away city') where the beryl gem from the nearby mountains were processed.

Thus, the identity of *vaidūrya* with beryl is well- established. It was known to be quite different from cat's eye. Kauṭilya listed beryl *vaidūrya* and cat's eye *mārjārakṣaka* as distinctly separate gem (AS2.11.30 and 39).

Kauṭilya never mentioned *marakata* (emerald, the darker green variety of *vaidūrya* or beryl) which used to be imported to India from Egypt probably after his era. In the post-Christian era, we find *vaidūrya* and *marakata* being mentioned together to mean the same family of green gem.

Vaidurya and Marakata

Kautilya was the first to describe the *vaidūrya* gem: "Beryl is of the colour of the blue lotus, of the *śiriṣa* flower, of the colour of water, green bamboo, parrot's wing" (*AS* 2.11.30).

While describing beryl as many-hued, Buddhabhatta emphasized that its principal colours resembled the neck of the peacock and greenness of bamboo (RP 203).

The family of beryl is a cyclosilicate $Be_3Al_2Si_6O_{18}$ which crystallises in the hexagonal system, sometimes occurring as long six-sided prisms, terminated by a basal plane (vide Kalidāsa's long grass-green *ratnaśalākā*). In pure from, beryl is colourless. Lattice substitution by a very small quantity of chromium (in the form of Cr^{3+}) makes the crystal light grass-green (typical *vaidūrya* of the early Sanskrit literature). Larger proportion of chromium (typically 0.2 per cent or above) results in intense green colour: 'beautiful and deep emerald green to grass-green, unrivalled in depth and brilliancy and comparable to the fresh green of a meadow in spring' (Bauer, 1968: 308).

This variety is well-known as *emerald* or *marakata* which was not mentioned by Kautilya and the best samples were imported later to India probably from Ethiopia, Egypt, and during the Muslim period, from Turkey. Lattice substitution by iron to the extent of 0.5 to 2 per cent makes the crystal light blue, and such natural crystals have been known as aquamarine or *Pāribhadra*. Greenish blue *utpalavarṇa* in *AS* 2.11.30 and *indīvara śyamavapu utpala* in *Manimālā* (p.510) is likely to be aquamarine. Ancient India was famous for the light-green as well as light blue beryl/aquamarine, the best supplies originating from Paddur, Kangayam and several other sites in the Coimbatore district. Beryl is also known to occur in yellowish green and pure golden yellow colour. *Marakata* or emerald became popular in India only after Kauṭilya's era. Probably, *marakata* or emerald was imported to India during the onset of the Christian era.

The Source and Etymology of Marakata

Though the occurrence of emerald in Ethiopia had been known to the ancients, the locality became completely forgotten. The earliest known emerald locality is in upper Egypt, not far from the coast of the Red Sea. The ancient mines discovered by Cailliaud in 1819 A.D. have been dated as early as 1650 B.C.; these are located in a depression of the long range of mountains which borders the west coast of the Red Sea. The mines are in Jebel (=Mountain) Sikait (also Sakketto, from Sanskrit Saikat?) and Jebel sabara (Zabara or Varvara in Sanskrit).

Pliny mentioned the rocks about Coptos, as containing the celebrated mines of the old. These mines, known as Cleopatra's emerald mines, located a little south of latitude 25^{0}N, were close to the sea-coast as well as the desert and known as such by the Indian traders (Bauer, 1968: 310-311).

The name *marakata* bears the imprint of *maru* (desert) and *kata* (from Pliny's "Coptos' or saikata meaning sea-coast or the mountain Sakketto?). In the justification of our hypothesis regarding the origin of word *marakata*, we may quote: Buddhabhatta (*Ratnaparikṣā* 150) mentioning marakata mine (*ākara*) past the sea- coast (*tīradeśe*), mountain Varvara and near the desert (*maroḥ samīpe*). Agastimata (287) and Ratnasaṃgraha (13) provide similar topographical descriptions. The name *marakata* also resembles *marukātār* and it may not be unlikely that some emerald was marketed across the desert (*maru*) around the state of Qatar.

The Mahābhārata (12.46.33) has used another name for emerald, and that is *masāragalu*, *masāra* or *masāraka*. Monnier-Williams explains in his Sanskrit dictionary that Egypt was named as *Miśar* or *Misar* in Sanskrit, and *galu* means a gem. Therefore *masaragalu* may be interpreted as the gem from Egypt, and that is consistent with the etymological origin of *marakatā* as suggested, for the first time, by us. The 4th century A.D. Prakrt text *Aṅgavijjā* (58.20) mentions *veruliya*, *maragata* as well as *masārakalla*, meaning beryl and emerald.

Emerald has few more name - equivalents in Sanskrit: *Harinmaṇi* (green gem), *Garuḍodgāra*, *Gārutmata*, *Pānnā* etc. The last three may be briefly explained. *Ratnaparikṣā* and *Agastimātā* narrated the myth or the folklore that gems had been derived from the body of the slain demon Bala: diamond from his bones, pearl from

the teeth, ruby from the blood, sapphire from the eyes, emerald from the bile etc. The mythical bird Garuḍa had taken the green bile of the demon in its mouth and then vomitted it (hence the name *Gārutmata* and *Garuḍodgāra*) on a mountain on the sea- coast near a desert beyond Barbara country'. We have earlier referred to Buddhabhatta's Sanskrit text (RP 150). *Agastimata* (285) mentioned Garuḍa as the king of the serpent-demon: '*pānnāgādhipaḥ*'. Pānnā also means something fallen down or dropped. Thus, the dropped bile of the serpent-demon or emerald also came to be known as *pānnā*. It is an open question whether the location of the famous diamond mine in Bundelkhand was named Pānnā because it also yielded some emerald or *pānnā*. It is quite possible that the place was named Pānnā to indicate emerald which resembles chrysoprase (nickel-containing compact quartz), widely occurring in the area, in greenness. The 100 ft deep old diamond mine at Majgoha (Majgama) south-west of Panna is now a cone- shaped depression filled with *green* mud. In this connection we also recall that Chanhu-daro showed light green beads and cups of fuchsite-quartzite which might have originated from Mysore. All these resemble beryl-like materials in their typical colour. The Sanskrit word *marakata* was the origin of *smaragdos* in Greek, *smaragdus* in Latin, *esmeralda* in Spanish and *emerald* in English.

Beryl and Emerald in Indian History

The popularity of green beryl or *vaidūrya* in ancient India is clearly revealed from the writings of Pāṇini, Kauṭilya and Patañjali. The Greek and Roman writers also attested to this fact. Rufus described king Saubhuti presenting 'his spectre made of gold and set with beryls' to Alexander (McCrindle, 1896, 1969: 220). Several Buddhist relic caskets contained semi-precious stones, quartz crystal, carnelian and malachite bird and beryl reliquary (as in 2nd century B.C. site of Bhattiprolu, near Guntur, Andhra Pradesh). The Buddhist monks and nuns were asked not to use shoes ornamented with, and bowls set with *vaidūrya* or beryl which must have been popular luxury commodities during the pre-Christian era (*Mahāvagga* 5.8.3; *Cullavagga*, 5.9).

Pliny of the first century A.D. wrote in his *Naturalis Historia* (37.5) that beryl was seldom found outside India, and that the Indians had discovered how to make counterfeit gems, and specially beryl, by staining crystal. Marshall has corroborated this through his observations on the Taxilan samples. Solinus of the third century A.D. drew upon Pliny, and wrote: "The Indians rub down the beryl into hexagonal forms in order to impart vigour to the dull tameness of the colour by the reflection from the angles. Of the beryl the varieties are manifold". The Greeks accompanying Alexander were surprised to note the Indians' fascination for green beryl which possessed only light colour. The Greeks might have introduced the Egyptian emerald of brighter greenness to the Indians who continued to import the same as *marakata* during the post-Christian era of trade with the Romans.

The *Ratnaśāstra* texts are full of poetic descriptions related to light green beryl, intense green emerald and bluish ultramarine: 'like the peacock's tail, the wing of the nīla- kaṇṭha, parrot's wing, moss, fresh grass, glow-worm's back, the sirisa flower' and so on (RP 152, 158-159; *Garuḍapurāṇa*, 1.71. 1- 29, *Manimālā*,

362-364 and 377-379). *Skanda Purāṇa* (23.135) categorised different kinds of beryl and emerald, and recorded the geographical locations of their mines.

The Antiquity of Diamond Mining in India

No C-14 dating of ancient diamond mine in India is available. Reviewing the position, Bauer (1968: 141) commented that the working of the most important diamond deposits known at present 'do not date back to very remote periods, probably in all cases subsequent to the year 1000 A.D. and sometimes much later'. We disagree on the basis of literary records, but do not have specific C-14 dates or archaeological evidences to counter Bauer's statement. *Fig. 1* shows the diamond fields in India as drawn in 1896 (Bauer: 1968,144). Possibly several of these sites were known in the ancient period.

Kauṭilya's *Arthaśāstra* of the late 4th century B.C. was probably the first text to describe the Indian diamond or *vajra* and the mode and area of its occurrence (2.11.37-41). The mine and stream deposits were listed as their sources.

It is hard to identify the precise locations of the place- names mentioned in Arthaśāstra, Bṛhatsaṃhitā, Ratnaparikṣā, Agastimata etc. regarding the diamond fields but we may conjecture the following locations: eighty miles south-east of Nagpur on the Sath river, a tributary of Wainganga (Vena of the Bṛhatsaṃhitā), the present Wairagadh, anciently known as Vajragṛha, the Kośala region of Ākarāvantī around the famous Pānnā in Madhya Pradesh, the region around the Golconda mines formerly known as Matanga, the Kalinga mine of Hīrā-Kund (literally means diamond mine), the alluvial sources from the Mahanadi in the Sambalpur district, the Koel river etc.

During the first century A.D., the precise source of the Indian diamonds was not known to the Roman traders, but later Ptolemy reported the diamonds coming from Sambalpur (Sabarae), the Sank branch of the Brahmani river, the Kośa or Kośala (panna) etc.

Diamond was used not only as gem but also as an abrasive. Gwinnett and Gorelick (1988: 187-193) have studied one of the seven rock crystal artifacts obtained from Arikamedu (dated not later than 300 A.D.) and proved that this 'lapidary training piece' was drilled with a twin diamond drill.

The drill holes were studied with a technique known as functional analysis, in which an impression of the hole was made using a silicone material. This model in effect turned the hole inside out. The impression was then coated with conductive gold and examined in an Amray 1000 Scanning Electron Microscope, and observations recorded on Polaroid film.

The details clearly revealed the use of diamond drills in processing hard rock crystal artifacts at Arikamedu.

Agate and carnelian were mined, processed and used even in the Pre-Harappan times. Yellowish varieties containing hydrated ferric oxide used to be dehydrated on heating and thus reddened to beautiful carnelian in an age-old practice. The best known deposits are found in the Rajpila hills at Ratanpur, on the lower Narmada river.

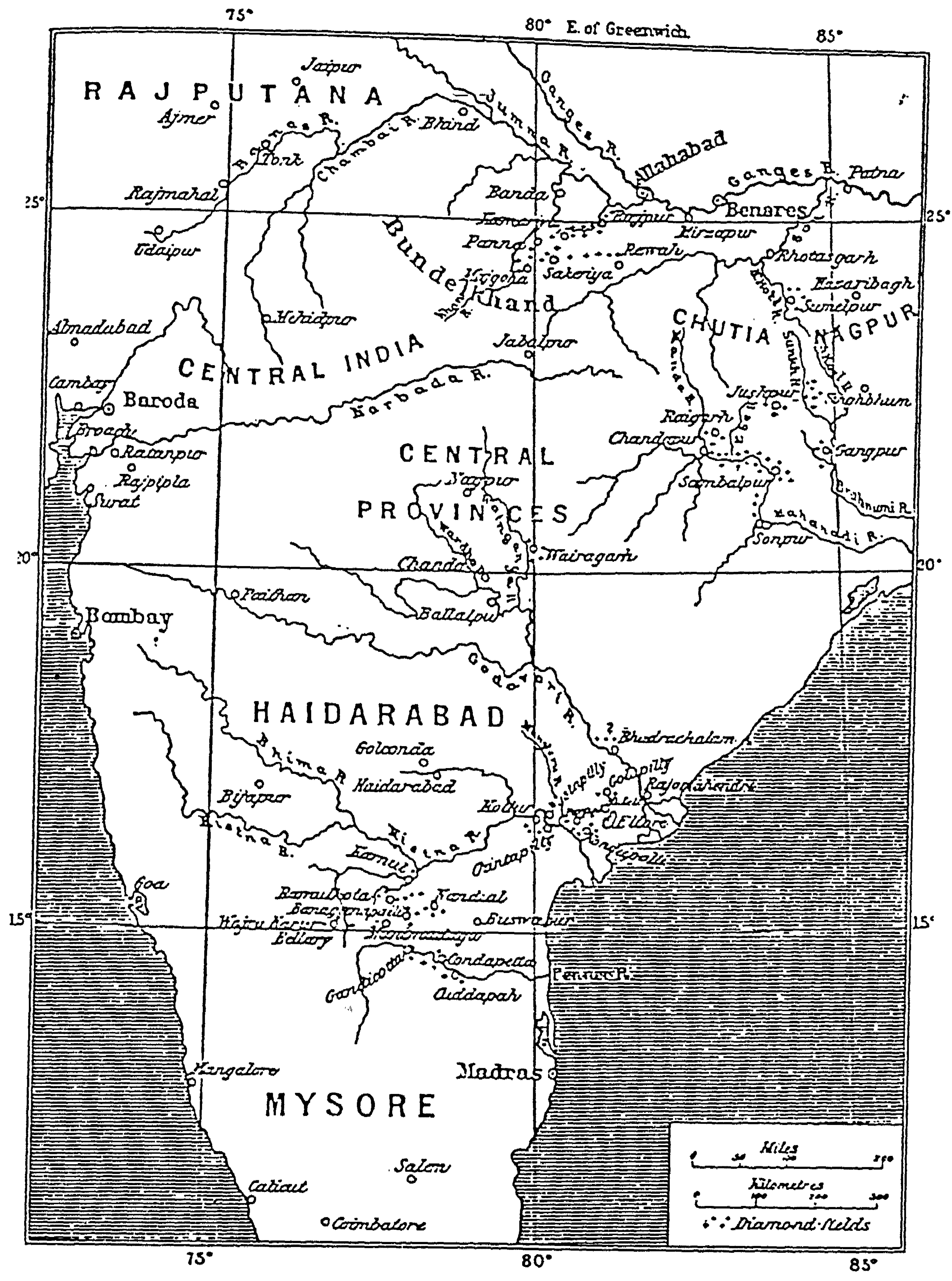


Fig. 1: Diamond-Fields of India (Bauer, 1968, p.144)

Ball (1881: 507-513) reported the Ratanpur mine shafts to be 4' ft in diameter and about 30' ft deep with galleries branching off on all sides.

Furthermore, Peyton (Paithan or Pratisthana) on the Godavari has been identified as Plithana of the Periplus (1st century A.D.) where agate and onyx used to be mined and sent to Broach for processing and export (Ball, 1881: 505).

We would now mention one non-gem mineral resource widely used in ancient India. The major source of sodium has been the riverine efflorescent alkaline *reh* deposits which ruin agriculture but aid industries. These natural deposits of *reh* salts, known as *khari* in Bihar, *kallar* in Punjab, *chavudu* in Andhra Predesh, were used in the ancient times for making glass, providing glaze in the NBPW ware etc.

Sāji Māṭṭi is the name of the crude mixtures of sodium salts lixiviated out of *reh* and concentrated, and sold for making soap, glass, detergents etc. Typical compositions of *reh*, *sāji māṭṭi* and salt lake bittern are given in Table 5.

Auden et al (1942) estimated that the *reh* - infested districts of Utter Pradesh alone produced 0.5 m ton Na_2CO_3, 0.6 m ton $NaHCO_3$ and 0.3 m ton Na_2SO_4. Similar data from other states have been compiled by Brown and Dey (1955).

Limited space does not permit us to discuss the huge variety of gem and non-gem minerals used in ancient India. Some idea regarding the enormity of the subject may be gleaned from the long list of post-Christian era Sanskritic words related to metals, gems and non-gem minerals (Biswas, A.K., 1991). We mention only a few non-gem minerals of commercial importance in ancient India: *adrija* (bitumen), *abhraka* (mica), *kajjali* (cinnabar), *karpūrarasa* (calomel), *kāṃksi* (alum), *kasisa* (green vitriol or ferrous sulphate), *kharpara* (zinc ore), *gandhaka* (sulphur), *gāndhāra* (red lead), *culikā lavaṇa* (sal ammoniac), *tankana* (borax), *tala* (orpiment), *tutthaka* (blue vitriol), *nilāñjana* (stibnite), *makaradhvaja* (mercuric sulphide), *manaḥśilā* (realgar) *mākṣika* (pyrite), *swarṇamākṣika* (chalcopyrite), *mṛddāraśṛṅga* (anglesite or litharge), *rasaka* (calamine), *rasakarpūra* (mercuric chloride), *rasasindura* (mercuric sulphide), *rasāñjana* (stibnite), *varāṭikā* (marine nodule), *vahnimṛttikā* (fire-clay), *vimalakā* (pyrite), *kāṃsya vimala* (arsenopyrite), *śilājatu* (bitumen), *sarjikā mṛttikā* (river-bed alkaline *reh*), *sasyaka* (blue vitriol), *sīsaja* (red lead), *suvarcikā* (borax), *srotānjana* or *sohta* (carrollite), *haritāla* (orpiment, also lӧllingite?), *hiṅgula* (cinnabar) etc.

Table 5 — Typical compositions of *reh*, *saji matti* and bittern (compiled from La Touche, 1912, Auden, 1942, and Brown and Dey, 1955)

	Moradabad *reh*	Meerut *reh*	Kanpur *saji matti*	Sambhar bittern	Lonar Lake incrustation fractions
Na_2CO_3	9.66	4.68	27.02	14.5	8.2-33.2
$NaHCO_3$	8.55	3.96	4.28	9.1	6.3-24.4
NaCl	1.92	3.88	-	28.6	28.0 (av.)
Na_2SO_4	8.66	1.19	33.98	40.5	2.0 (av.)
				K_2O	4.3-10.3

D. On Some Metalliferrous ores in Ancient India

A large number of metallic artifacts have been unearthed from the archaeologically excavated sites in India. Some of them might have been imported; circumstantial evidences suggest however that most of them were made indigenously from their respective ores in the sub-continent.

Table 1 lists some of the C-14 dated ancient mines in India starting from the earliest (so far recorded) 1260 B.C. Rajpura- Dariba in Rajasthan, a mining area which yielded complex ores containing, lead silver, zinc and possibly copper also. The table lists other dated mines which produced metalliferrous ores containing Cu, Zn, Pb, Ag, Au etc. Elsewhere, we have listed 38 other mines of copper, definitely ancient though undated (Biswas, A.K., 1991). The chalcolithic cultures of the Mature-and Post- Harappan era produced bronze objects containing tin, the source of which has not been precisely determined. Some tin ore could have been imported from the well-known mines of Afghanistan and Iran during the Harappan era, and again later during the prosperity of Taxila (Chakrabarti, 1979).

Some tin ore could have been mined indigenously from Rajasthan, Karnataka and Bihar (Brown and Dey, 1955: 167-68). Cassiterite, SnO_2 is often found in the form of water- concentrated placer deposits, referred to as 'stream tin'. Tylecote (1962: 63 quoted by Hegde) suggested that the ancient metallurgists might have exploited (and exhausted) placer deposits of 'stream tin' rather than vein deposits which are hard to mine. Such surface accumulations in the proximity of the Aravalli and Chota Nagpur Hills might have been amongst the sources of tin in ancient India.

Similarly, there are several possible sources of lead and silver. The Harappans were acquainted with lead ores such as galena (sulphide) and cerussite (carbonate), and their smelting process which is simple on account of easy reducibility and low melting point of the metal.

At Mohenjo-daro, six percent of the tools contained lead; a fraction of the tools contained arsenic which was evidently derived from lollingite, samples of which have been found in the Harrappan sites.

In view of the fact that silver artifacts from the Mature-and Post-Harappan sites as well as Taxila contained lead and trace of sulphur, it may be surmised that the source was argentiferrous galena ore. A few samples of silver in the Harappan sites and the silver plates of Gungeria, showing some gold but no lead, were probably derived from the South Indian electrum deposits.

We have provided the C-14 date of 760 B.C. for the Hatti gold field in *Table 1*. There is no earlier date for gold-mining in India than this. Probably the bulk of gold during the Harappan and even the Historical Periods in India was derived from alluvial washings, a practice widely observed as late as the nineteenth century (Ball, 1880). Table 1 contains several C-14 dates for the zinc-lead ore mines in Rajasthan such as Rajpura- Dariba, Rampura-Agucha, Zawarmala etc.

The Issue of Ore-Artifact Correlation

In pursuing the laudable objective of establishing that the metals were produced indigenously in ancient India, our archaeologists have sought correlation between

the artifacts and ores in the subcontinent in terms of trace metal impurities. Most of the enthusiastic investigators ignored the cautionary remarks of Thomson (1958) pointing out the hazards in ore-correlations, and occasionally reported 'positive correlation'.

We have pointed out (Biswas, A.K. et al, 1990: 50-51) that the correlation depends upon: (a) the type of ore, oxide or sulphide or silicate, the nature of impurities, (b) the precise conditions of smelting, such as temperature, nature of fuel, flux etc., and several other factors.

The ore types may very even within a region of small area. Hegde (1968) failed to detect the impurity elements of Cr, Co, Ni, Bi and Mo (present in the Devnimori silver coin) in the nearby Zawar argentiferrous galena ore and concluded that the silver was 'imported'. Shekar (1983) however found them in the Ambamata deposit only a hundred kilometres away!

So far as the occurrence of metallic artifacts in the ancient sites are concerned, the existence or absence of mines in the neighbourhood areas in the modern age hardly establishes any truth. On the one hand, the currently known mines might have been unknown to the ancient people, and on the other, some small near- surface reserves might have been thoroughly exploited by the ancient miners, so that we do not know them at present. Certain impurities such as arsenic might have been eliminated through certain simple pre-smelting operations such as roasting. Thus we are not sure whether arsenic-free copper ingots of Lothal were made at Oman as claimed by S.R. Rao (1979 & 1985) or made out of Indian arsenic-bearing ore after a pre-smelting roast.

Having stated the hazards of the ore-metal correlation, let us report some of the 'positive correlations' obtained by our archaeo-metallurgists. Friedman et al (1966) claimed that with regard to copper artifacts, the elements of Ag, As, Bi, Fe, Sb and Pb were the most important metallic impurities in relating the metal back to the original type of ore. Following this argument, Agrawal (1971, 1984) suggested that Chanhu-daro celt and Mohenjo-daro spearhead were made from Khetri chalcopyrite ore, since all the three materials contained trace impurities of Sb, Pb, but not Fe and As.

Hegde (1969) compared the artifacts from Ahar with the chalcopyrite ore from Khetri, and the similarities led him to conclude that 'copper metal of the Ahar artifacts was probably smelted from the ore of the Aravalli region'. The slag dumps and neighbouring mines indeed suggest that copper was made at Ahar indigenously, but Hegde's argument is unsound. 'The Aravalli region' alluded to by Hegde corresponds to a vast area and ores of more than one type; it is hard to believe that chalcopyrite ore was brought all the way from Khetri to Ahar over a distance of hundreds of kilometres while there were ores in the vicinity.

Hegde (1985, 1989) has himself modified his earlier view and suggested that the Ahar artifacts were possibly made from the *nearby* region of the Aravalli which constitutes of not-too-hard tremolite-chlorite schists rather than the far-off Khetri ore embedded in quartzite rocks, hard and less easily extractable. While impurity patterns of the ores in different parts of the Aravalli 'may be similar' (the previously stated Ahar-Khetri correlation now loses much of its significance), the lead isotope

ratios markedly differ in the north-eastern, central, and south- western parts of Aravalli (Hegde, 1985). Efforts are in progress to correlate metal artifacts and specific ore deposits through lead isotope ratio analysis.

Further cautioning is necessary in this regard. The ancient smelting process, which is not definitely known at present, would certainly have considerable effect of the trace element profile as proven by smelting experiments (Tylecote et al, 1977). Lead isotope correlation between ore and artifact has been successful in one case (Gale et al, 1982). Reporting failure in another case, Craddock (1985: 59) has rightly questioned that lead in the artifact could come not only from the copper ore (as presumed) but also from the flux and deliberate addition of lead during smelting.

We do not discourage attempts for ore-artifact correlation, but these must be supplemented with additional evidences for (a) mines of antiquity, (b) outfits for smelting, furnaces and crucible, (c) heaps of slag and slag-ore correlation regarding the non-metallic phases, and (d) a reasonably large number of artifacts at different stages of manufacture and of composition and properties varying within narrow limits (Biswas, A.K. et al, 1990: 51). Fortunately, several such evidences for indigenous metallurgy in India have been obtained from Mehargarh, Ganeshwar-Jodhpura, Lothal, Ahar, Khetri (for copper), Chanhu-daro and Lothal (for beads and seals), Atranjikhera, Ujjain (for iron), Zawar (zinc, lead and silver) etc.

Some Observations on the Metallic Slags in Ancient India

There are heaps of ancient slag in the excavated sites which conclusively prove indigenous smelting in India. A detailed examination of the slags and slag-ore correlation as suggested above (c) should help us in ascertaining the kind of ores and fluxes which might have been used during the process of smelting.

During the excavation of Period I levels at Ahar, heaps of slag-like material were recovered from more than one trench at three different depths. Evidently the copper smelting industry at Ahar was extensive. The analysis of the slag is:

SiO_2	35.2-38.2 p.c	MnO_2	1.2-2.3
$Fe_2O_3 + FeO$	43.9-48.3	CuO	0.7-0.9
MgO	2.4-3.6	SO_3	3.6-6.1
Al_2O_3	5.3-7.8		

Evidently, complete removal of sulphur and recovery of copper were not possible, and the ore was sulphidic. Copper ore from the neighbouring area contains less than 20 p.c. silica and therefore it may be presumed that the copper ore was fluxed with silica during smelting (Hegde, 1969).

It is unfortunate that *phase studies* were not conducted on the Ahar slag. The modern Khetri Copper Plant produces slag which contains phases such as magnetite Fe_3O_4 and copper ferrites such as $CuFeO_2$, $Cu_6Fe_3O_7$ and some free copper oxide (Sharma and Shekhawat, 1984). Similar phase studies on the ancient slag would have shown whether (a) such a slag could have been derived from the neighbouring

ore containing specific gangue meterials and (b) if so, what temperature and other physico-chemical conditions might have been employed.

Atranjikhera showed not only iron objects but also furnace and iron slags assaying 64-67 p.c. Fe_2O_3, 25-30 p.c. SiO_2, 3-5 p.c. Al_2O_3, 1-3 p.c. CaO, 0.6-0.9 p.c. MgO and O.7 p.c. P_2O_5 (Gaur, 1983: 496).

It has been proposed that iron could have been made from the iron-bearing shales occurring in the neighbouring Agra-Gwalior range which assays 21.7 p.c. Fe, 41.9 p.c. SiO_2, 14 p.c. Al_2O_3, 6.3 CaO. 2.3 MgO, 1.4 Na_2O and 6.8 p.c K_2O. This suggestion (Gaur, 1983: 487-500) is plainly unacceptable, since the proportions of SiO_2, Al_2O_3, CaO and MgO are lower in the slags, and iron percentage much higher, than in the iron shale. The raw material must have been rich iron ore (from eastern Uttar Pradesh or Bihar) out of which the iron recovery was incomplete and inefficient on account of solid-state reduction.

Excavation by Willies et al (1987, 1989) has revealed ancient mining of the Rampura-Agucha deposit (25° 50′ N, 74° 44′ 15" E) in Rajasthan. There is the clear base of a gossan at about 15 m. depth from which marmatite, pyrite and sphalerite (ZnS) were selectively oxidised and leached by the natural agencies leaving galena-cerussite-anglesite ore-body enriched in terms of silver.

The ancient mining timbers have been C-14 dated as 370 and 250 B.C. Tiwari et al (1984:85) have proved that here mining done at the 80-125m. depth was selective following lead mineralisation and pure galena veins in preference to the zinc ore veins.

There are huge slag dumps in the Rampura-Agucha area. The petrographic thin sections of slag sample indicate the presence of quartz and feldspar grains which have not undergone much change. Evidently, low-temperature smelting was done which could have yielded argentiferous metallic lead; the main target was possibly silver.

The slag dump area also showed several cylindrical retort-like pieces with inside coating of dirty white $ZnSO_4$ and slag assaying 0.01 p.c. zinc and as high as 9.30 p.c. lead. Considering the fact that the ore-body assays 12p.c. Zn and 2-3 p.c.Pb, Paliwal et al (1986) rightly inferred that an appreciable amount of zinc must have been recovered by retort distillation process which was perfected in the Zawar Mines.

At Agnigundala, Andhra Pradesh, extensive mining, mineral processing (crushing, grinding and beneficiation) and smelting (of copper and lead) took place in ancient India which is evident from the rock dumps, slag heaps, cupolas and crucibles (Ziauddin, 1961: 120). The ore must have been complex and multi-metallic. Similarly, selective mining of the Ambamata deposit might have resulted in recoveries of copper, lead and silver, and zinc which was strikingly rich in cadmium (Shekar, 1983).

One of the most spectacular discoveries during the recent eighties related to mining archaeology and archaeo-metallurgy has been the reconstruction of the glory of zinc ore mining and smelting in ancient India (Biswas et al, 1984; Craddock et al, 1985; Willies, 1987 & 1989; Hegde, 1989 etc.). Limited space does not permit us to present the full report which is available elsewhere (Biswas, A.K., 1991). Only

a few brief comments may be made here with reference to the 13th century A.D. ancient slags in Zawar mine, Rajasthan.

There are at least sixteen deposits of ancient slag around the Zawar Mine, which are basically of two types; (a) glassy and (b) crystalline. The first variety resulted on account of smelting and recovery of lead and silver but not zinc.

At a later stage, the value of zinc was realised, sphalerite removed carefully from the lead ores and reduced/distilled in retorts leaving some residual slag. Pyrite used as flux precipitated in the crystalline slag as fayalite (Freestone et al, 1987).

Detailed X-ray and electron diffraction studies were conducted on the Zawar retort residue (content), wall and (lead) slag (Biswas, et, al, 1984). The phases identified are reported in *Table 6.*

It is evident from the data that a small part of sphalerite was not converted into oxide and remained in the retort as ZnS and $ZnSO_4$. The presence of goslarite or $ZnSO_4$, $7H_2O$ (hydrated at later stage) was confirmed by the endothermic DTA peaks apart from X-ray and electron diffraction studies. Some ZnO was converted to complex silicates during roasting and some underwent atmospheric conversion at a later stage to the basic carbonates (vide Table 6). Trace element detection in the zinc residue/slag by the Energy Dispersive X-ray Micro-Analysis or EDAX in the Scanning Electron Microscope showed the existence of elements such as Na, K, S, Ti etc., which must have originated from the ore-body charged into the retort.

The above-mentioned work on zinc-lead slags illustrates that valuable information may be obtained by sophisticated techniques regarding the nature of

Table 6 — Phases identified in Zawar Retort Residue (Content), Wall and (Lead) Slag by X-Ray and Electron Diffraction Studies (Biswas *et al* 1984: 236).

	Phases identified	
Sample	X-ray diffraction	Electron diffraction
Retort content	$Zn_2P_2O_7$. $5H_2O$ goslarite $ZnSO_4$, $7H_2O$ hemimorphite, Zn_4 $(OH)_2$ Si_2O_7, H_2O esperite Ca_3Pb $(ZnSiO_4)_4$ Sphalerite ZnS, chalcopyrite $CuFeS_2$ larsenite, Pb $ZnSiO_4$	$Zn_2P_2O_7$. $5H_2O$ goslarite hemimorphite, esperite, quartz, Mg_2 $Al_4Si_5O_{18}$, hardistonite $Ca_2ZnSi_2O_7$, hydrozincite or aurichalcite, $Zn_5(CO_3)_2$ $(OH)_6$
Retort wall	Goslarite, hardistonite, hemimorphite $Zn_2P_2O_7$. $5H_2O$, aurichalcite, quartz, sphalerite	Goslarite, hemimorphite, Willemite Zn_2SiO_4, hardistonite
Slag	Quartz, goslarite, $Zn_2P_2O_7$. $5H_2O$ hemimorphite, aurichalcite, sphalerite, chalcopyrite, hardistonite.	Hemimorphite, goslarite, hydrozincite, quartz, sphalerite

the ore and reduction/smelting techniques, the details of which are outside the purview of this paper.

Electron diffraction studies have further shown that the complex Zawar ore contains not only sphalerite (α- and ß ZnS) and galena (PbS) as the major phases but also red silver, pyrite, chalcopyrite, anglesite ($PbSO_4$), $PbCO_3$, calamine or $Zn_4(OH)_2Si_2O_7$, H_2O etc. (Biswas, A.K., 1981). The gangue impurities are dolomite, quartz and white mica.

E. The need for further studies

In the beginning of this article we mentioned (A) the nature of evidences related to gems and minerals in ancient India. Four categories of evidences were referred to:

(i) archaeological excavations and related data,

(ii) evidences of industrial activities,

(iii) mining archaeology, and

(iv) literary evidences.

We have provided only a glimpse of the first three categories of evidences, the fourth category which is corroborative of the rest, having been exhaustively reviewed elsewhere (Biswas, A.K., 1991). Further studies and research on all the four categories of topics are called for.

In future, all archaeological excavations should be exhaustive - both vertically as well as horizontally - unearthing *all* possible material evidences. The artifacts as well as rejects, residues, wastes like slags etc. should be thoroughly examined by sophisticated techniques and equipments like electron microscope. It may be noted that many ancient Indian gems, minerals and metallic artifacts discovered in the 19th and early 20th century have not yet been subjected to phase studies; this is very important and should be done now. Identification of the ancient gems by the earlier mineralogists should be now corroborated by fresh X-ray and electron microscopic studies.

As we have illustrated in this article, research on the ancient slags is likely to yield rich dividends. Attempts for ore-artifact and ore-slag correlations should be continued as a part of a comprehensive programme and not as an exclusively isolated piece of investigation. Mining archaeology in India is in a state of infancy. We should look for more C-14 dates particularly around the ancient mines which have not been dated so far. A deeper search into the Sanskrit, Pali, other Indian language (such as Tamil) literatures and also into the early Greek and Roman records is likely to enrich our knowledge further vis-a-vis the ancient Indian technologies related to gems and minerals.

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Mercurial and Metallic Compounds

DAMODAR JOSHI

Introduction

The present study includes a survey of Vedic literature followed by classical literature of Ayurveda such as *Caraka Saṃhitā* and *Suśruta Saṃhitā*, *Aṣṭāṅga Hṛdaya* (7th century A.D), *Rasa Hṛdaya Tantra* (8th/9th centuries A.D), *Rasārṇava Tantra* (10th century A.D), *Cakradatta* (11th century A.D), *Rasendra Cūḍāmaṇi* (12th century A.D), *RasaPrakāśa Sudhākara* (12th century A.D) and *Rasendra Cintāmaṇi* (12th century A.D) to assess the development of mercurial and metallic compounds in historical perspective and the technology involved in their pharmaceutical processing and preparation.

In Vedic period the metals of therapeutic importance are found mentioned, but, their compounds of therapeutic value were not seen. There is no reference of mercury also in Vedic literature. However, in the classical age of Ayurvedic medicine mercury, metals and their compounds are found referred to for external and internal uses though, to a very limited extent only. As regards the technology involved in their pharmaceutical preparation it may be said that it was in developing stage only upto the time of *Aṣṭāṅga Hṛdaya* (7th century A.D) and till then no significant progress could be seen.

From 8th/9th century A.D onwards, the development of *Rasa Śāstra* (Advanced Ayurvedic Pharmaceutical Science) takes place with regards to the processing and the use of mercury, metals, minerals and many of their compounds for alchemical as well as therapeutic purposes. Many new methods/procedures/techniques for the treatment of mercury, metals/minerals were developed to convert these into pharmaceutically most suitable forms/compounds which are non-toxic, highly absorvable and most effective in therapeutics.

It is important to mention here that initially the development of *Rasa Śāstra* was started to achieve the objectives of *Lohavedha* (alchemy) to remove poverty from the world and in this respect the great Indian alchemist Nagarjuna and his followers - Nandi, Govinda, Bhagavatpāda, Somadeo, Yaśodhara, Nityanātha and Dhuṇḍhukaṇṭha etc. have contributed much and took this branch of learning and

practice to its great heights and developed a number of mercurial and metallic compounds. Incidently during this period some scholars started to use these compounds for *Deha vedha* (transformation of body tissues) purposes also, considering the *samyatva* (similarity) between *loha* (metal) and *deha* (body) or *loka* (world) and *purūṣa* (man). They observed highly encouraging response in their efforts. In this way the mercurial and the metallic compounds have found their uses in the therapeutics of Ayurveda. Further, in this period, primarily the mercurial and metallic compounds have been used for the promotion of positive health only but slowly these are found highly useful for the prevention and cure of diseases also.

Further, while using these compounds in the body, the scholars have also felt that still there is a need and scope for the development of more advanced and sophisticated pharmaceutical techniques for removing the toxicity of mercury, metals and minerals and for their conversion into the most suitable compounds of therapeutic value. Besides these in the context of mercury the development of *Mūrcchanā* and *Gandhaka Jāraṇa* also deserves mention. As through these the toxicity of mercury could be reduced to minimum and mercury may be converted to some compound form which may prove to be the most suitable for internal use. It is found mentioned in *Rasendracintāmaṇi* for the first time that through the process of *Mūrcchanā* only the *vyādhighatakatva Śakti* (disease destroying capacity) could be induced in mercury and its compounds. As prior to the development of this process (*mūrcchanā*) mercury is being used internally or externally mixed with metals and herbal drugs either in amalgam form or divided into fine particles form.

It is worthwhile to mention here that *kajjali* and *parpaṭi* in which mercury converts into black sulphide compound are though, found mentioned in *Cakradatta* (11th A.D) however, their systematic preparation and frequent use in therapeutics could be seen only during 12th century A.D i.e. after the development of *Mūrcchanā* process in Indian Pharmaceutics. Further the *Kūpipakva rasāyanas* (mercurial compounds of red sulphide type) prepared through *Bālukā Yantra* system of heating in *kāca kūpi* (glass bottle prepared specifically) could be prepared only after the development of *Mūrcchanā* process. Besides a few apparatuses and a specific heating system/method is also found referred to in *Rasendra Cintamani* (12th century A.D). The *Rasa Sindura*, *Makaradhvaja* and *Rasa Karpūra* are some of the examples of *Kūpipakva rasāyanas* and deserve mention in this context.

Thus, in short it may be said that besides eight or eighteen *Saṃskāras* (special processes) of mercury, the *Śodhana*, the *Māraṇa*, the *Satvapatana*, the *Druti*, the *Jāraṇa*, the *Mūrcchaṇā* and the *Bhāvanā* & *Puṭapāka* etc. are some of the important pharmaceutical processes developed in medieval period for the preparation of mercurial and metallic compounds of therapeutic importance.

Historically the mention of mercury in literature could only be seen since the time of Classical literature of Ayurveda i.e. *Saṃhitās*. In this period a few mercurial compounds are found referred to specially for external application and one or two for internal uses. But in medieval period many mercurial compounds are being prepared and used in Ayurvedic therapeutics. During this period mercury is also considered to consist of many *doṣas* (impurities) which were recognised to produce many *vikāras*/diseases/bad effects in the body. Hence, before recommending its

internal uses in the body ancient scholars have advised to treat mercury with various *saṃskāras* (special processes) to remove its *doṣas* (toxic effects) and to potentiate it further to make it more suitable for internal use in the body for achieving *Rasāyana* (rejuvenating) effect (total positive health) and also remarkable therapeutic effects.

The metals Gold, Silver, Copper, Iron, Lead and Bell metal (an alloy of metals) are found mentioned in Vedic literature. During Vedic period there is no mention of metallic compounds of therapeutic value for internal use. Of course there are references of some metallic compounds in Vedas to be used for other purposes such as for making utensils, ornaments, war implements and other instruments, etc.

Then coming down to the classical age of Ayurvedic medicine again there are references of six metals only i.e. *suvarṇa* (Gold), *rajata* (Silver), *tāmra* (Copper), *kṛṣṇayasa* (Iron), *trapu* (Tin) and *śīśā* (Lead) alongwith *lohamala/mandura* (Rusted iron) or *lohamalas* (slag part of all the later five metals except gold). In this period these are included in *bhauma/pārthiva* group or in *trapvadi* group. Further, in this period number of metallic compounds are found referred to for internal uses to achieve *Rasāyana* as well as therapeutic effects. In this period metals are mostly used for obtaining Rasayana effects and less commonly for therapeutic effects. Their processing methods are also found described in this period though, from pharmaceutical point of view these may not be considered as very suitable in converting metals for internal use and probably for this reason only their uses are found very much limited. In this period the metals could be processed in such a way that these are reduced to collyrium like fine powder form or sometimes to solution form.

Then coming down to the period (i.e. 8th-9th century A.D and onwards) the '*śodhana*' and '*māraṇa*' processes are developed, through which their toxic effects are reduced to minimum possible level and the metals are converted to an ash form or to a desired compound form through the effect of some chemical reactions taking place during their processing either through grinding with or without liquids/vegetable extractives and/or heating through '*puṭa*' system. In this period innumerable mercurial and metallic compounds are prepared and used for obtaining Rasayana as well as therapeutic effects. Thus, the period between 8th/9th century A.D to 12th century A.D may be considered as the golden period for the development of mercurial and metallic compounds of therapeutic value and their technology.

Mercurial and Metallic Compound in Caraka Samhita

In *Caraka*, metals/minerals are enumerated under '*pārthiva/bhauma*' group of drugs. The metals gold with five other metals like silver, copper, iron, tin and lead alongwith their mala (mandura/loha kiṭṭa) and in mineral sand, calcium compound, realgar, orpiment, gems, salts, hematite/red ochre and galena are described.

As regards their uses these are used externally or internally for obtaining Rasayana effects and for curing various diseases. During the period of '*Caraka Saṃhitā*' the metals are advised for internal use in the form of very fine powder i.e. as fine as '*añjana*' (Collyriums) applicable to the eyes.

The method of converting iron or other metals into very fine powder form is also found described in *Caraka* (*Ci.* 1/3/15-23). Though, initially this method is described with reference to iron only, however, afterwards it is advised to be followed commonly for all the metals (Gold, Silver and Copper etc.) to convert these into fine powder form.

Description of Method

The pieces of thin iron sheets are made red hot and quenched in cold *Triphalārasa*, Cow's urine, Kṣāra or *Lavana drava*, *Iṅgudi kṣāra drava* and *Kiṃśuka kṣāra drava* serially for number of times or till their very fine powder like that of *Añjana* (Collyrium) is made. These powders mixed with honey and *āmalaka* juice may be kept in an earthen pot anointed with ghee for one year under the heap of barley grains and then be used internally with honey and ghee.

A. Metallic Compounds Consisting Gold

1. *Brāhma Rasāyana* (*CS. Ci.* 1/1/58) is a compound of Gold, Silver, Copper and Iron alongwith Coral powder and indicated for Rasāyana purpose.

2. *Aindra Rasāyana* (*CS. Ci.* 1/3/24-29) is a compound of Gold and contains gold powder in two *yava* (barley grain) quantity.

3. *Lohādi Rasāyana* (*CS. Ci.* 1/3/15-23) is in fact not a metallic compound rather through this the method of converting metals into *Añjanābha* (Collyrium like) fine powder form and their method of internal use as Rasayana are described. Though, this method is mainly described for Iron it may also be applicable in case of other metals like Gold, Silver and Copper etc.

4. *Triphalā Rasāyana IV* (*CS. Ci.* 1/3/46-47) is a gold compound or compound of all the other metals (Tin, Lead, Copper, Silver and Iron). In this the metals are used in fine powder form.

5. *Indrokta Rasāyana* (*CS. Ci.* 1/4/22-23) is a compound of Gold, Silver, Copper and Iron. In this fine powder of metals is used in 1/16th part alongwith Coral, Quartz, Pearl, Cat's eye and Conch Shell powder.

6. *Nyāgrodhādi Leha* (*CS. Ci.* 27/30) is a Gold compound and contains gold powder alongwith other drugs and indicated for *Urustambha* (Stiffness of thigh).

7. *Savarṇīkaraṇa Lepa* (*CS. Ci.* 25/116) is a Gold compound to be applied as paste externally and contains Gold powder and *Rasottama* (mercury).

8. *Varṇakara Lepa* (*CS. Ci.* 25/117) is a Gold compound and contains Hematite, Copper and Ferrous Sulphate in addition to gold powder.

9. *Hema Cūrṇa* Prayoga (*CS. Ci.* 23/239-240), this Gold powder alone is advised for internal use for nutralising the effect of poisons and also of copper powder.

B. Other Metallic Compounds

1. *Harītakī yoga* (*CS. Ci.* 1/1/77) is an Iron compound in which $^1/_4$th part of iron powder is used alongwith other drugs.

2. *Nigrahīta rasa* (*CS. Ci.* 7/72) is a compound of mercury advised for internal use in *Kuṣṭha roga* (leprotic skin lesions) but according to some scholars it is doubtful.

3. *Madhvāsava* (*CS. Ci.* 7/73-75) is an Iron compound prepared by fermentation process and indicated in *Kuṣṭha roga*. It contains Iron powder and advised to be prepared in Iron pot.

4. *Triphalādyariṣṭha* (*CS. Ci.* 12/39-40) is an Iron compound and contains Iron powder.

5. *Gauḍoriṣṭha* (*CS. Ci.* 12/39-40) is an Iron compound and contains Iron powder.

In these *Asavāriṣṭha* preparations Iron powder is also advised to be mixed from the beginning itself and allowed to remain there till the completion of the process. It may be presumed here that during fermentation process iron added may get dissolved in the liquid by some kind of chemical reaction. thus, this is another kind of method for using metals internally, i.e.in solution form.

6. *Mahānīla Taila* (*CS.Ci.* 26/270-272) is an oily iron compound in which Tīkṣṇa Loha Cūrna is added alongwith *Kāśīśa* (ferrous sulphate).

7. *Jīvantyādi leha* (*CS. Ci.* 18/176-177) is an Iron compound - contains iron powder and indicated in *Kāsa*.

8. *Dārvyādi leha* (*CS. Ci.* 16/97) is an Iron compound - contains iron powder and indicated in *Kāmalā* and *Pāṇḍu*.

9. *Pathyādi leha* (*CS. Ci.* 16/98) is an Iron compound, - contains iron powder and indicated in *Kāmalā* and *Pāndu*.

10. *Triphalādyava leha* (*CS. Ci.* 16/99) is an Iron compound, contains iron powder and indicated in *Kāmalā* and *Pāṇḍu*. These are other medias of using iron metal internally. That means through oily and sugar based medias the iron metal was being used in ancient times.

11. *Kṛṣṇatvakāra lepa* (*CS. Ci.* 25/115) is an iron paste compound which contains Iron and Ferrous Sulphate.

12. *Tryūṣanādi Cūrṇa* (*CS. Ci.* 12/42) is an Iron compound indicated for *Tridoṣaja Śopha*.

13. *Navāyasa Cūrṇa* (*CS. Ci.* 16/70-71) is an Iron Compound in which 9 parts of Iron powder is used and indicated for *Paṇḍu* & *Kāmalā*.

14. *Yogarāja* (*CS. Ci.* 16/80-86) is an Iron compound and indicated for Rasāyana Karma. It contains iron powder alongwith purified Chalcopyrite, *Rupyamala* and *Silajatu*.

16. *Muktādya Cūrṇa* (*CS. Ci.* 17/125-128) is a metallic compound and indicated for *Śvāsa*, *Kasa* and *Hikkā*. It contains Copper, Iron, Silver and Lead alongwith Pearl, Coral, Cat's eye, Quartz, Conch Shell, Galena, Sulphur and Salts.

17. *Kṣāra Guḍicā* (*CS. Ci.* 12/43) is an Iron Compound and indicated in *Śopha*.

18. *Magadhyādi Rāsāyana* (*CS. Ci.* 30/150) is an Iron compound indicated for Rasāyana Karma.

19. *Sarvākṣiroganut Varti* (*CS. Ci.* 26/246) is an Iron and Copper compound alongwith Conch Shell, Coral and Cat's eye powder. It is indicated for applying in eye lids as *Añjana* (Collyrium).

20. *Pippalyādi yoga* (*CS. Ci.* 18/74) is an Iron compound and indicated in Śleṣmalā yonī.

21. *Sūkṣma Tāmra rajaḥ proyoga* (*CS. Ci.* 23/239), in this fine powder of Copper is advised for internal use for producing emasis (vomiting) in cases of poisoning due to the ingestion of poisons mixed with food. It is followed by *Hema Cūrṇa prayoga.*

22. *Kuṣṭhādi lepa* (*CS. Ci.* 7/117-118) is a paste compound prepared in Copper vessel and kept for one week in copper vessel before use. It contains Realgar and Ferrous sulphate.

23. *Saindhavādi lepa* & *Triphalādya lepa* (*CS.Ci.* 26/280-282) are paste compounds indicated for applying on head and contain Iron powder.

Mineral Compounds

In *Caraka Saṃhitā* number of mineral compounds are found referred to. As minerals also contain one or other or more metals as their constituents, hence these may also be taken as metallic compounds and as such are also being described here.

1. In *Caraka Saṃhitā* (*CS. Ci.* 1/3/48-65) a detailed description of *Śilājatu* (a famous mineral Bituman) obtained from Himalayan mountains as an exudate is found mentioned which consists of its origin, varieties and properties. It is also mentioned in the same context that the varieties of *Śilājatu* are based on its metallic contents i.e. *suvarṇa*, *raupya*, *tāmra* and *loha śilājatu.*

2. Further in *Caraka Saṃhitā* (*CS. Ci.* 12/49) *Silajatu parayoga* is mentioned for *Tridoṣaja Śotha.* And there are number of other compounds in which *Śilajātu* is included as one of the constituent.

3. *Makṣika yoga* (*CS. Ci.* 7/70) is a Chalcopyrite compound indicated for *Kuṣṭha roga.*

4. *Gandhaka yoga* (*CS. Ci.*7/71) is a Sulphur compound indicated in *Kuṣṭha roga.*

5. *Kanakakṣīrī taila* (*CS. Ci* 7/111-116) is an oily preparation, indicated in skin lesions, contains Orpiment, Copper Sulphate, Zinc ore, Alum and Ferrous Sulphate.

6. *Kuṣṭhādi lapa* (*CS. Ci.* 7/117-118) is a past compound for external application and contains Realgar and Ferrous Sulphate.

7. *Vipādikāhara Taila/Ghṛta* (*CS. Ci.* 7/120) is an oily preparation and contains Copper Sulphate.

8. *Manaḥ Śilādi Ghṛta* (*CS. Ci.* 17/145-146) is a ghrta preparation and contains Realgar.

9. *Punarnavā Maṇḍūra* (*CS. Ci.* 16/93-96) and *Maṇḍūra Vaṭaka 1 & 2* (*CS. Ci.* 16/72, 102-104) are the compounds of purified *Maṇḍūra*(Rusted iron powder)and indicated for *Pāṇḍu* and *Kāmalā*

10. *Puṣyānuga Cūrṇa* (*CS. Ci.* 30/90-95) is a *Gairika* (Hematite) compound indicated in *Yonidoṣa* and *Rajodosa.*

11. *Kāśīśa Cūrṇa* (*CS. Ci.* 30/122) is a compound of ferrous Sulphate and Alum and indicated in *Picchilā yoni.*

12. *Tāpyādi Cūrṇa* (*CS. Ci.* 16/78-79) is a Chalcopyrite, Bituman, *Ayomala* (*Maṇḍūra*) and Silver compound and indicated in *Pāṇḍu roga.*

13. *Yogarāja* (*CS. Ci.*16/80-86) is a compound of Chalcopyrite, *Śilājatu* and *Rūpyamala.*

14. *Manaḥśilādi ghṛta* (*CS. Ci.* 17/145-146), *Viḍaṅgādi leha* (*CS. Ci.*18/52) and certain *Dhuma yogas* (*CS. Ci.*18/69-75) are Realgar or orpiment compounds.

15. *Bālaka yoga* (*CS. Ci.* 20/32-33) indicated for *Pittaja vami.*

16. *Śāli Cūrṇa yoga* (*CS. Ci.* 20/39) indicated for *Pittaja chardi.*

17. *Muktādya Pradeha* (*CS. Ci.* 21/81-82) indicated for *Visarpa roga.*

18. *Kṣārāgada* (*CS. Ci.* 23/78-79) indicated for all types of *Viṣas.*

19. *Somavalkādi lepa* (*CS. Ci.* 23/220) indicated for *Viṣas.*

20. *Khadirādi gudikā* (*CS. Ci.* 26/210) indicated for *Mukha roga.*

21. *Puṣyānuga Cūrṇa* (*CS. Ci.* 30/90-95) indicated for *yonidoṣa* and *rajodoṣa* is the compound of *Gairika/Suvarna Gairika/Lohamṛt* (Hematite/Red-ochre) which is also an iron compound and the main source of Iron.

Thus, in short it may be said that during the period of *Caraka Saṃhitā* six metals are known. Of these five metals except gold are said to contain some kind of *malas* (impurity/slag). In *malas* '*Ayomala*' *Mandūra* (Rusted iron/Iron oxide) is given much importance in therapeutics. Besides metals a few minerals were also in common use for therapeutic purposes, such as - *Śilājatu, Kāśīśa, Gairika, Tuttha, Kharpara, Haritala, Manāḥsila, Kāṅkṣi, Añjana* (Galena), *Rasāñjana* (Solid extract of *Darvikvatha*), *Suvarṇa Makṣika* and *Gandhaka.*

Apart from minerals the following gems were also in use in therapeutics, viz. - *Mani* in general, *Muktā* (Pearl), *Pravāla* (Coral), *Saugandika Māṇikya* (*Ruby*), *Vajra* (Diamond), *Vaidūrya* (Cat's eye), *Sphatika* (Quartz) & *Śaṅkha* (Conch Shell) etc.

As regards mercury and its compounds it may be said that mercury and mercurial compounds are not commonly referred to in this text, only at one place *Nigrahīta rasa prayoga* is found mentioned for internal use but it is also doubtful and at one place *Rasottama* term (may be denoting mercury) is found referred to in a paste yoga for external use. Hence it may be said that in the period of Caraka Saṃhitā mercury is found used for external application only. Further it may be pointed out that this external use of mercury is also found mentioned in the portion redacted by Drdhavala. Thus in this period of caraka the metals are used either in powder form converted to a very fine state of sub- division by heating the metals to red hot and quenching these into cold liquids (decoctions/juices/alkaline liquids) several times and then powdering finely. These metals are also used in solution form by putting iron powder into the liquids of *Āsava* and *Āriṣṭha* preparations and keeping it into the contact of liquid through out the process (3-4 months) or till its complete

dissolution. These (metals) are also used through oily media and sugar base mixed with *lehya* preparations, and also as paste after rubbing on stone.

In Caraka Iron is used frequently in number of preparations (compounds) for therapeutic and Rasāyana purposes. Besides Iron, Gold, and Silver are also used in many compounds. Their vessels are also advised to be used for keeping the drugs. And the metals are also used for making the equipments and instruments. Copper is also used but less commonly for the above purposes. The Lead compounds are also found referred to for internal use and external application.

In minerals, mostly the Iron and Copper containing compounds and also Arsenic containing compounds find frequent uses in therapeutics. The use of lead and-zinc containing compounds is less common. In other minerals the use of '*Śilājatu*' is more frequent. The use of Copper powder, in case of poisoning produced by the use of poisons mixed with food materials, for inducing vomitting and doing *Hṛdviśodhana* is worth mentioning. Here the use of Copper was followed by the internal use of Gold powder to neutralise the toxic effects of copper and also of the other poisons. Both these uses of Copper and Gold by 'Caraka' are worth mentioning.

Mercurial and Metallic Compounds in Suśruta Saṃhitā

The review of this text revealed that there are number of metallic compounds but no mercurial compound suitable for internal use is found referred to in this text. Besides metallic compounds seven metals (gold, silver, copper, bell metal, Iron, tin & lead) are found described under '*Trapvādigaṇa*'(*SS.Su.*38/30) This text has also described the common properties of the drugs of '*Trapvādi*' group. Not only this the properties of each metal (*SS. Su.* 46/360-365) are also found described here, which are not seen in earlier text (*Caraka Saṃhitā*). Apart from metals a few minerals and their compounds are also found described under '*Uṣakadigaṇa*' (*SS. Su.* 38/18), the drugs of gem group in '*Manivarga*' (*SS. Su.* 46/366) and the types of Salts in 'Lavaṇa Varga' (*SS. Su.* 46/343).

In '*Usakādigaṇa*', *Uṣaka* (Alkaline earth), *Saindhava* (Rock salt), *Silajatu* (Bituman), *Kāśīśadvaya* (Kasisal Puspaka Sisa) and *Tutthaka* (Blue Vitriol) are included. In 'Maṇi group', *Mukta* (pearl), *Vidruma* (Coral), *Vajra* (Daimond), *Indra* (Sapphire), *Vaidūrya* (Cat's eye) and *Sphaṭika* (Quartz) are enumerated alongwith their properties. In *Lávaṇa* group' - *Saindhava*, *Sāmudra Viḍa*, *Sauvarcala*, *Romaka* and *Audbhida* varieties of salt are included alongwith a brief description of each variety (*SS. Su.* 46/346-351). Further the properties of *Ṭaṅkana* (Borax (*SS. Su.* 46/359) are also found described here.

Metal processing method

In addition to the processing method of metals in general and Iron in particular is also found described in this text by the term '*Ayaskrti* (*SS. Ci.* 10/11-14) which is of three types, viz.

1. *Ayaskṛti*, 2. *Auṣadhāyaskṛti* and 3. *Mahauṣadhāyaskṛti*

Method of Making Ayaskṛti

For this thin sheets of *Tīkṣṇa* variety of Iron are first pasted with the paste of different salts and then heated strongly in cow dung fire and quenched in the decoctions of '*Triphāla*' and '*Sālasāradi* group' of drugs repeatedly for sixteen times. There after these are heated in *Khadirāṅgāra* (strong heat) and on cooling these are made into fine powder form by grinding and sieving through a fine cloth. It is known as '*Ayaskṛti*' and may be used in suitable doses mixed with ghee and honey.

Ausadhayāskṛiti

For '*ausadhāyaskṛti*' strongly heated pieces of thin Iron sheets are quenched in the decoction of Tṛvrit etc. drugs, kept in a boat shaped tub made of *Palāśa* wood repeatedly for twenty one times. There after Iron pieces should be kept in a *thālī* (wide mouth vessel) with the above liquid and heated over cow dung fire till the liquid reduces to $^1/_4$th part and filtered. This filtrate may again be used for quenching hot iron sheets pieces repeatedly. In the end mix *Pippalyādi* powder one part, ghee and honey two parts each with the treated Iron in an Iron pot and keep it in secret place for sometimes. It is known as '*Auṣadhāyaskṛti*'.

Mahauṣadhāyaskrti

For '*Mahauṣadhāyaskrti*' strongly heated pieces of thin iron sheets are quenched in the decoction of *Śālasārādigaṇa* drugs kept in a boat shaped palāśa wood tub for twenty one times. On cooling so treated iron pieces are ground to a fine paste from with the above decoction. Now mix $^1/_4$th part of above decoction with it and fill it in an already prepared earthen pot. Add *Pippalyādi Cūrṇa* in a quantity sufficient to develop a pungent taste of the liquid or equal to Iron paste or in double amount. Keep it in a calm place for one month or as required. It is known as '*Mahausadhāyaskṛti*' similar to *Āsavāriṣṭha* preparation.

Besides different methods of making '*Ayaṣkṛties*', another method of using Iron internally is also found described in Susruta in the context of '*Lohariṣṭha*' (*SS. Ci.* 12/11).

In this context small pieces of thin *Tīkṣṇa loha* scats, obtained after strong heating are advised to be added with the liquid of '*Lohāriṣṭha*' since the beginning of the fermentation process and is allowed to remain in contact with the liquid for 3-4 months (i.e. till the completion of the fermentation process) or till complete dissolution of thin Iron pieces is achieved in the liquid and on developing a specific taste of the liquid it may be taken for use.

It means during samhita period (classical age-1000 BC - 500 BC) Iron was also advised to be used in solution form through *Āsavāriṣṭha* preparations. Not only this the Iron and Copper powders were also advised for internal use mixed with *leha* (liking) type of compounds. The *Sālasārādi leha* (*SS. Ci.* 12/9) deserves mention in this context.

Metallic Compounds

A. Gold Compounds

The number of gold compounds are referred to in this text in different contexts, viz. -

1. *Bilva Suvarṇa yoga* (*SS. Ci.* 28/9-10) is a gold compound recommended for removing *Alakṣmī* (misfortune).

2. *Padma Bījādi yoga* (*SS. Ci.* 28/13) is a gold compound, recommended to remove *Alakṣmī* (misfortune) and misery.

3. *Nīlotpalādi yoga* (*SS. Ci.* 28/14) is a gold compound, recommended for removing *Alakṣmī* (misfortune) and misery.

4. *Vacābilvādi yoga* (*SS. Ci.* 28/16) is a gold compound, recommended for improving *Medhā* (intelligence) and *Āyu* (longevity).

5. *Gopayas Madhūcchiṣṭadi yoga* (*SS. Ci.* 28/15) is a gold compound recommended for *Rasāyana Karma.*

6. *Madhvamalaka yoga* (*SS. Ci.* 28/19) is a gold compound recommended for destroying *Āriṣtha Lakṣaṇas* in severe diseases.

7. *Śatāvarī ghṛta prayoga* (*SS. Ci.* 28/20) is a gold compound to make the kings under control.

8. *Gocandanādi yoga* (*SS. Ci.* 28/21) is a gold compound recommended to produce *Saubhāgya* (fortune).

9. *Padma Nīlotpala Sarpi* (*SS. Ci.* 28/22) is a gold compound recommended to prolong Āyu (longevity).

10. *Mahākalyāṇaka Ghṛta* (*SS. Utt.* 39/118-119) is a gold and gem compound indicated in *Jwara.*

B. Iron Compounds

1. *Navāyasa Cūrṇa* (*SS. Ci.* 12/10) is an Iron compound in which nine parts of iron powder (equal to nine herbal drugs) is mixed.

2. *Mārkavādiyoga* (*SS. Ci.* 19/20) is an iron and copper compound indicated for *upadaṃśa* (Gonorrheal type infection).

3. *Śāla Sārādi leha* (*SS. Ci.* 12/9) is an Iron and Copper compound and indicated in all types of *Pramehas.*

4. *Lohariṣṭha* (*SS. Ci.* 12/11) is a fermented liquid preparation, in which strongly heated thin Iron pieces are added and allowed to remain in the solution till these get dissolved in the solution. It is indicated in *Meha, Pāṇḍu* diseases etc.

C. Mineral Compounds

As almost all the minerals contain some or the other metals in them hence their compounds are also being described here.

1. *Saurāṣṭryadi Cūrṇa* (*SS. Ci.* 19/19) indicated for *upadaṃśa*, contains hematite, Copper sulphate, white iron sulphate, Galena, orpiment, Realgar, Alum and Rock Salt etc. minerals.

2. *Gundrā bhasma yoga* (*SS. Ci.* 19/20) indicated for *Upadaṃśa* contains orpiment and Realgar.

3. *Tuttha Kāśīśādi Cūrṇa* (*SS. Ci.* 19/20) indicated for Vraṇa and Visarpa contains copper and Ferrous Sulphate, Realgar and Rasanjana etc. minerals.

Thus, in *Suśruta Saṃhitā* more advancement in the knowledge of using metals in metallic compounds could be seen.

A. In this text the metals and minerals are described under different groups depending upon their nature and types. Such classification of the drugs of mineral origin is not seen in '*Caraka Saṃhitā*'. The *Trapvādigaṇa, Uṣakadigana, Manivarga* and *Lavanavarga* etc. deserve mention in this context.

B. The common properties of the drugs of these groups and the specific properties of individual metals and minerals included in these groups have also been found described in this text for the first time.

C. Further this text has used the term '*Ayaskṛti*' for the first time for the method through which metals are converted into the pharmaceutical form suitable for internal use.

D. Three methods for making '*Ayaskṛties*' mentioned in this text indicate that further modification in the processing method of metals has taken place with a view to make them more suitable for internal use.

E. In addition to '*Ayaskṛti*', a form of metals advised for internal use, the other method of using metals internally (solution form) is also found mentioned in this text, while describing the *Āsavariṣṭha* preparations.

F. The iron etc. metals were also advised to be used in oily media and in *Avaleha* media in this text.

G. For increasing *Medhā, Āyu, Ārogya* and Fortune and to prevent *Alakṣmī* (misfortune) and diseases nine gold compounds preparations are found mentioned in this text.

H. No mercurial compound suitable for internal use is found referred to in this text.

Mercurial and Metallic Compounds in Aṣṭāṅga Hṛdaya

'*Aṣṭāṅga Hṛdaya*' (7th century A.D.) is also an important text of Ayurvedic Medicine written by Vāgbhaṭṭa Junior in about 7th century A.D. though, it is a compilation of the ideas and subject materials dealt with by 'Caraka' and 'Suśruta', it has described the important aspects of Ayurvedic medicine in a very concise form. In this text metals and minerals are not found described under the heading of any group.

From the historical point of view it may be considered as a land mark (last limit) for using the metals in *Rajas/Cūrṇa* (powder) form. In this text Mercury (*Pārada*)

is also found referred to by the terms '*Pārada* and '*Rasottama* for both internal and external uses mixed with other drugs.

Mercury Compounds

It is evident from the study of *Aṣṭāṅga Hṛdaya* that in this period (7th century A.D.) the mercurial compounds have found place in the therapeutics for both internal and external uses.

Mercurial Compounds for Internal Use

1. *Śilājatvadi rasāyana* (*Ast Hr. Utt.* 39/161) is a compound of mercury, iron and a few other minerals indicated for internal use for obtaining rasāyana effect and to provide nourishment to the weak body tissues.

2. *Mañjiṣṭhādi taila* (*Aṣṭ. Hṛ. Utt.* 32/31) is again a mercury compound advised for internal use in cases of *Nīlaka* and *Vyanga* of the diseases of face. In addition to mercury it contains Red Ochre, Realgar, Orpiment and a few herbal drugs.

Mercurial Compounds for External Use

1. *Kālīyākādi lepa* (*Aṣṭ. Hṛ. Utt.* 25/61) is a compound of mercury used as paste for applying externally on skin. It is also known as *Savarnakara lepa* and recommended for making color of the skin of affected part similar to the healthy skin. In this compound the term '*Rasottam*' is used for denoting mercury.

2. *Nayanāmṛtāñjana* (*Aṣṭ. Hṛ. Utt.* 13/36) is also a compound of mercury and lead and recommended for using as *Añjana* (Collyrium) in the *Timira roga* of eyes.

Metallic Compounds

A. Gold Compounds - In this text number of gold compounds are found mentioned and these are advised for using in newly born children to elderly persons.

Gold compounds for children

1. *Tapta Rajata-Tapanīya Nimajjita Koṣṇa Jala* (*Aṣṭ. Hṛ. Utt.* I/7). It is a slightly hot water prepared by quenching red hot gold and silver sheets in water. It is advised for using the same for the bath of newly born child.

2. *Vacādi Cūrṇa* (*Aṣṭ. Hṛ. Utt.* I/7) is a gold compound prepared by mixing gold leaves/powder with prescribed herbal drugs and recommended for use in newly born child for improving its *Bala* and *Medhā*.

3. *Hemadhātri Cūrṇa* (*Aṣṭ. Hṛ. Utt.* I/9) is a gold compound prepared by mixing gold with *Dhātri* (*Āmalaka*) *Cūrna*. It is recommended for internal use in newly born child.

4. *Vacādi, Arkapuspyādi, Matsyakṣādi* and *Kaidaryādi prasa* (*Ast.Hṛ.* I/47-48) are the four gold compounds advised for internal use in children upto one year for increasing their strength, body tissues, complexion and intelligence.

5. *Tāpyasuvarṇa leha* (*Aṣṭ. Hṛ. Utt.* 35/56) is a gold compound of leha type. In this gold and chalcopyrite powders are mixed with honey and sugar for making as *leha*. It is recommended for use in *Sarvayogajavisa*.

6. *Hemaprayoga* (*Aṣṭ.Hṛ.Su* 7/27-27). In this the use of gold powder is advised after doing *Hrdviśodhana* by the use of copper powder to neutralise the effect of poisons used with foods in general and *Garaviṣa* in particular and to prolong life span.

7. *Triphalā Rasāyana* (*Aṣṭ. Hṛ. Utt.* 39/42-43) is a gold compound alongwith five other metals and recommended as rasayana.

8. *Pancaravinda rasāyana* (*Aṣṭ. Hṛ. Utt.* 39/48) is a gold compound and contains other drugs also, it is recommended for rasayana purpose.

9. *Catuṣkuvalaya ghṛta* (*Aṣṭ. Hṛ. Utt.* 39/49) is a gold compound containing gold leaves with other drugs and recommended for rasayana karma.

10. *Brāhmī rasāyana* (*Aṣṭ. Hṛ, Utt.* 39/50) is a gold compound and contains gold powder in yava quantity alongwith other herbal drugs.

11. *Cūrṇāñjana* (*Aṣṭ. Hṛ. Utt.* 13/45) is an Anjana type gold compound in which silver, quartz, gems, lead compound (*Srotonjaña*) copper, Iron, Red Ochre and Conch shell are included in addition to gold. It is recommended for all types of eye diseases for applying in eyes.

B. Iron Compounds

1. *Navāyasa loha* (*Aṣṭ. Hṛ. Ci.* 16/14-15) is an iron compound in which *Ayorajas* (Iron powder) is used in nine parts (equal to all the herbal drugs) and indicated for *Pāṇḍu* and *Kāmalā*.

2. *Triphalā rasāyana* (*Aṣṭ. Hṛ. Utt.* 39/42-43) is an Iron compound contains Iron alongwith other metals and indicated as rasayana.

3. *Vākuci rasāyana* (*Aṣṭ. Hṛ. Utt.* 39/107) is an iron compound contains *Loha Cūrṇa* (iron powder) alongwith herbal drugs and indicated as rasayana.

4. *Śilājatvādi rasāyana* (*Aṣṭ. Hṛ. Utt.* 39/161) is an Iron compound and also contains mercury and other minerals and indicated as best rasayana.

5. *Nāra Siṅgha Ghṛta* (*Aṣṭ. Hṛ. Utt.* 39/169-173) is an Iron compound indicated for rasāyana and *Vājīkaraṇa* purposes, contains Iron pieces and advised to be prepared in iron vessel.

6. *Maṇḍūra Vaṭaka* (*Aṣṭ. Hṛ. Ci.* 16/16-19) is a compound of *māṇḍura* (Rusted iron), also contains Tāpya (Chalcopyrite) and indicated for *Pāndu.*

7. *Tāpyādi Cūrṇa* (*Aṣṭ. Hṛ. Ci.* 16/20-22) is a compound of silver and Rusted iron, also contains Tapya and Śilajatu indicated in *Pāṇḍuroga*.

8. *Dhātryādi leha* (*Aṣṭ.Hṛ.Utt.* 39/149) is an Iron compound indicated to preserve youthfulness.

9. *Ayorajaḥ prayoga* (*Aṣṭ. Hṛ. Utt.* 34/55) is an Iron compound indicated in *Picchilā yonī.*

10. *Loha Viḍaṅga leha* (*Aṣṭ. Hṛ. Utt.* 39/150) is an Iron compound indicated for making the man youthful with black hairs.

11. *Tāmra rajaḥ prayoga* (*Aṣṭ. Hṛ. Su.* 7/27) here copper powder mixed with honey is advised for internal use for *Hṛdviśodhana* in cases of food poisoning for producing vomiting. And it is followed by *hema curna* prayoga for neutralising the effect of poisoning of Copper and also of *Garavisa* and to prolong life span.

C. Mineral Compounds

Just like *Caraka* and *Śusruta saṃhitā* there are many mineral compounds found referred to in this text of *Aṣṭāṅga Hṛdaya*. These are being mentioned here on account of their metal content. The important minerals referred to are *śilājatu* (Bituman), *tāpya* (Chalcopyrite), *haritāla* (Orpiment), *manaḥśilā* (Realgar), *gairika* (Hematite), *añjana* (Galena), *tuttha* (Blue Vitriol), *kāśiśa* (Green Vitriol) and *kāṅkṣī* (Alum) etc.

1. *Śilājatu rasāyana* (*Aṣṭ. Hṛ. Utt.* 39/130-142). Here *Śilājatu* is described in detail mentioning its place of origin, varieties, properties, *Śodhana* method, the method of its uses, dose schedule and its superiority in therapeutics than the other drugs. It is considered best for achieving rasayana effect.

2. *Candrodaya Agada* (*Aṣṭ. Hṛ. Utt.* 35/24) is compound of Galena, Orpiment and Realgar and indicated as anti poisonous agent.

3. *Manjiṣṭhādi taila* (*Aṣṭ. Hṛ. Utt.* 32/31) is a compound of Alum,

Orpiment, Realgar, Hematite and Copper Sulphate and indicated for improving the complexion of the face.

4. *Kāśīśādi yoga* (*Aṣṭ. Hṛ. Utt.* 34/55) is a compound of Alum and Green bitriol indicated for cleansing *yoni*.

5. *Tutthakādi lepa* (*Aṣṭ. Hṛ. Utt.* 34/4-5) is a compound of Copper Sulphate, Ferrous Sulphate, Orpiment, Realgar, Heamatite, Rasanjana, Alum, and common salt and indicated in *Upadaṃśavraṇa*.

6. *Pearl yoga* (*Aṣṭ. Hṛ. Utt.* 37/27) is a compound of Pearl in the form of paste and applied in burning sensation caused by poisons.

7. *Anti-poisonous Gem* Compound(*Aṣṭ. Hṛ. Utt.* 36/90) In this group of gems is indicated for destroying the effect of Snake poison. The gems are - *Karketana* (Ruby), *Marakata* (Emerald), *Vajra* (Diamond), *Gajamuktā* (Pearls obtained from elephant), *Vaidūrya* (Cat's eye), *Gardabha Maṇi* (Gem obtained from donkey) and *Serpamaṇi* (Gem obtained from snake).

A few more mercurial and metallic compounds:

1. In this text many mercurial compounds are found referred to for both (internal and external) uses. The mercurials for internal use are not found mentioned in earlier texts.

2. In this text gold and its commpounds are frequently and commonly found indicated for the use in newly born child to improve its *bala* (resistance), growth and intelligence.

3. For Rasayāna purposes and increasing the *Āyu* (life span) number of gold compounds are found referred to in *Medhāyus kāmīya rasāyanādhyāya*.

4. More number of metallic and mineral compound could be seen referred to in this text.

5. Various precious stones are found referred to in this text and were recognised for their anti-poisonous effects.

Description of Mercurial and Metallic Compounds (from 8th century A.D. to 12th century A.D.)

For collecting mercurial and metallic compounds of medicinal importance following source materials or texts have been studied:

1.	Rasa Hṛdaya Tantra	Govinda Bhagavatpada	8/9th AD
2.	Rasārṇave Tantra	Unanimous	11th AD
3.	Cakradatta	Cakrapāṇi	11th AD
4.	Rasendra Cūḍāmani	Somadeva	12th AD
5.	Rasa Prakāśa	Sudhākar Yaśodhara	12th AD
6.	Rasendra Cintāmaṇi	Dhuṇḍhuka Nātha	12th AD

1. Rasa Hṛdaya Tantra (8/9th century. A.D)

This text is written by Shri *Govinda Bhagavatpāda* in about 8/9th century. A.D. The major portion of this text is devoted to describe *Pārada Saṃskāras* (18 special processes of Mercury).

The 19th chapter of this text had dealt about the internal uses of Mercury. It is clearly mentioned here that if mercurial compounds for achieving Rasāyana effects are used without subjecting with *kṣetrikaraṇa* procedure then these neither produce desired effects in the body nor prove beneficial to the human tissues, instead produce various kinds of *doṣas* (toxic effects) all over the body.

Forms of Mercury Recommended for internal use

It is also mentioned in 19th Chapter of this text that Mercury may be used internally either in '*Āroṭa*' (Purified form) or in *Bhasma* (ash) or *Baddha* (solidified forms).

Mercurials for Internal Use

1. *Kalkīkrta Sūtayoga* I (*RHṛ*. 19/19)

   Here purified Mercury mixed with *Mākṣika* (Chalcopyrite), *Śilājatu* (Vitumen), *Loha Cūrṇa* (Iron powder partially converted to Iron Oxide), *Haritakī Cūrṇa, Bibhitakī Cūrṇa, Vidāṅga Cūrṇa, Ghee* and *Honey* made into paste form may be used internally to prepare body suitable for mercurial therapy.

2. *Kalkikṛta Sutayoga* II (*RHṛ*. 19/20)

   Here purified mercury is mixed with *Ghana* (Mica), *Kānta loha* (Magnetic Iron), Ghee and Honey made into paste form is advised for internal use to achieve *Amaratva* (immortality) and *Kṣetrīkaraṇa* effect.

3. *Ghana Satvādi Baddha Pārada yoga* I (*RHṛ* 19/34)

   Here Mercury madė solid by mixing and consuming ¼ part of *Abharaka Satva* & *Kānta loha* and equal part of *Tīkṣṇa Loha* is recommended for internal use to obtain *Kṣetrikaraṇa* effect.

4. *Ghana Satvādi Baddha Pārada Yoga* II (*RHṛ*. 19/35)

   Here Mercury made solid by mixing and consuming *Abhraka Satva, Kāntaloha bhasma* and *Suvarṇa bhasma* and triturated with *Satavari* juice is advised for internal use alongwith Ghee & Honey.

5. *Mrta Rasendra Yoga* (*RHṛ* 19/37-38)

   Here Mercury is made tọ consume *Abhraka, Sasyaka, Makṣika, Rasaka, Darada, Vimala, Vajra, Silājatu, Vaikrānta, Kānta, Tīkṣṇa, Suvarṇa, Rajata, Pittala* and *Tāmra* and then reduced to ashes is recommended for internal use.

Doses of Mercury for internal Uses (RHr 19/40)

It is mentioned in this text that Mercury which has consumed and assimilated various metals and minerals, may be used internally in 1 *guñjā* to 1 *māsa* dose.

Compounds of Mercury & Metals

1. *Amara Sundarī Gutikā* (*RHṛ* 19/65-66)

   It is a compound of *Kānta Loha, Abhraka Satva*, Gold, Silver, Copper and Mercury and advised for internal use.

2. *Mṛta Sañjīvanī Guṭikā* (*RHṛ* 19/67-72)

   It is a compound of mercury, lead, gold, magnetic iron and metallic contents of Chalcopyrite and Mica.It is made into *Guṭikā* form (pills) and advised for internal use.

3. *Vajriṇī Gutikā* (*RHṛ* 19/73-74)

   It is a compound of mercury, *Kānta loha satva, Abhraka satva*, Copper, Gold, Silver and Diamond and made into *Gutikā* form and advised for internal use.

4. *Khecarī Guṭikā* (*RHṛ* 19/75-76)

   It is a compound of mercury and of superior precious stones. It is made into *Gutikā* form and advised for internal use.

Besides mercurial processes and compounds the metals and minerals found useful in mercurial processes, have been classified in different groups and described as follows:

Metals

In this text nine substances are described as metals and have been classfied in two groups, viz. 1. *Sāraloha* and 2. *Pūtiloha* groups. In *Sāraloha* group - Gold and Silver are included. In *Pūtiloha* groups - Copper, Brass, Steel iron, Magnetic iron, Cast Iron, Tin and Lead are included.

It is also mentioned in this text that the metals included in *Pūtiloha* group needs *Śodhana* (purification).

Minerals

Sixteen mineral drugs are described and classfied in the following two groups, viz. *Mahārasa* group and *Uparasa* group. Each group consists of eight drugs. In *Mahārasa* group :

1. *Vaikrānta* 2. *Kānta* 3. *Sasyaka* 4. *Mākṣika* 5. *Vimala* 6. *Adrija* 7. *Darada* and 8. *Rasaka* are included.

In *Uparasa* group - 1. *Gandhaka* (Sulphur) 2. *Gairika* (Hematite) 3. *Śilā* (Realgar) 4. *Āla* (Orpiment) 5. *Ksiti* (Alum) 6. *Khecara* (Ferrous Sulphate) 7. *Añjana* (Lead sulphide) and *Kaṅkuṣṭha* (*Viraṅga*) are included.

Besides above mentioned minerals following *Lavaṇas* (salts) and *Ksaras* (alkaline substances) are also found mentioned in this text, viz.

Salts : 1. *Saindhava* (Rock Salt) 2. *Sāmudra* (Sea Salt) 3. *Culhikā lavaṇa* (mixture of Sodium & Potassium Salts) 4. *Sauvarcala* (black salt) 5. *Romaka* (śalt of alkaline earth) and 6. *Biḍa lavaṇa* are included.

Alkaline substances : 1. *Swarji Ksara* (Sodium Bicarbonate mineral) 2. *Tankana Kṣāra* (Borex) 3. *Yava Kṣāra* (Alkaline material obtained from burning of Barley plant).

These metals and minerals are advised for internal use only after treating these with *Śodhana* and/or *Māraṇa* processes.

Procedures for Śodhana Process

Here *Śodhana* is not restricted to chemical purification only as it is seen often that in many cases some impurities are added to the materials during *Śodhana* process and thus, in the context of Indian Medicine (Ayurveda) *Śodhana* means removing of toxic materials/unwanted materials from the drugs which are not found useful for the body and also adding something with the drugs subjected to *Sodhana*. For this, the following procedures are generally used.

Procedures

1. *Tāpana & Nirvāpa* (Heating and quenching in liquids) (*Fig.1*)

2. *Swedana* (Boiling in liquids) (*Fig.2*)

3. *Drāvaṇa* and *SecanaḌhalana* (Melting and pouring in liquids) (*Fig.3*)

4. *Kṣārāmla Kalka Lepana* and *Agnidhmapana* (Pasting and heating in strong heat)

5. *Dravana* and *Vāpana/Jāraṇa* (Melting and Sprinkling of drugs) (*Fig.4*)

6. *Bhāvanā* (Meceration/trituration with liquids) (*Fig.5*)

7. *Bhāvanā* and *Putana* (Trituration and Heating in a closed *Sampuṭa*) (*Fig.6*)

8. *Agni Tāpana* and *Utphullana* (Removal of water of crystallization by heating and puffing).

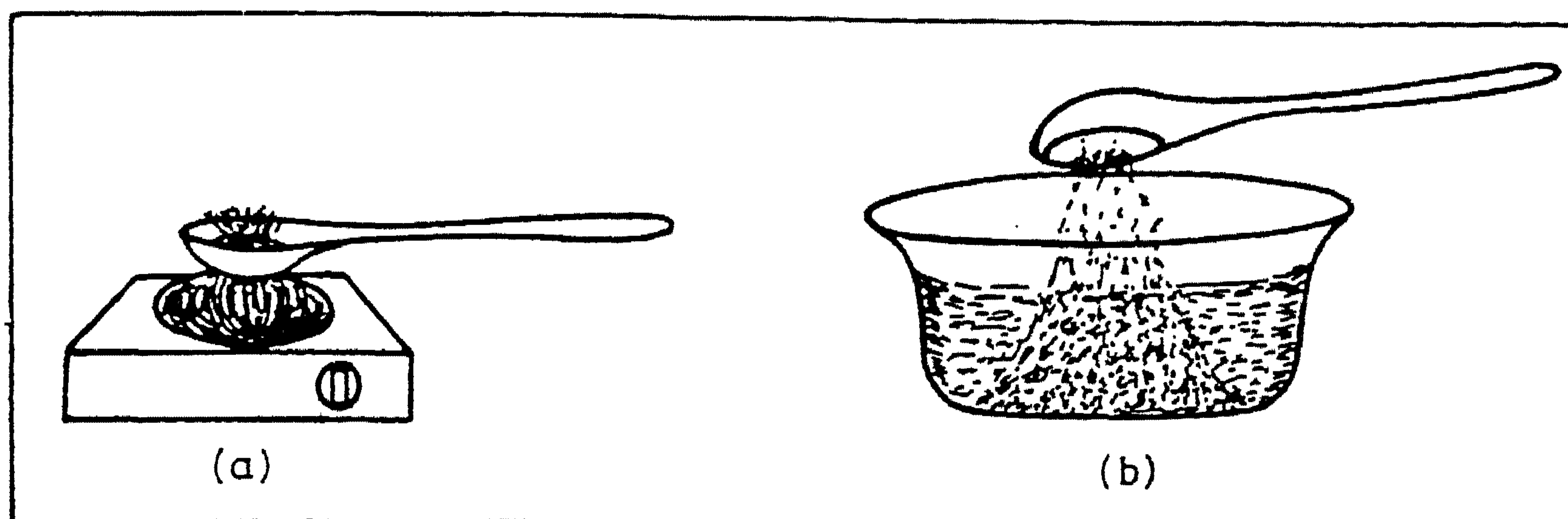
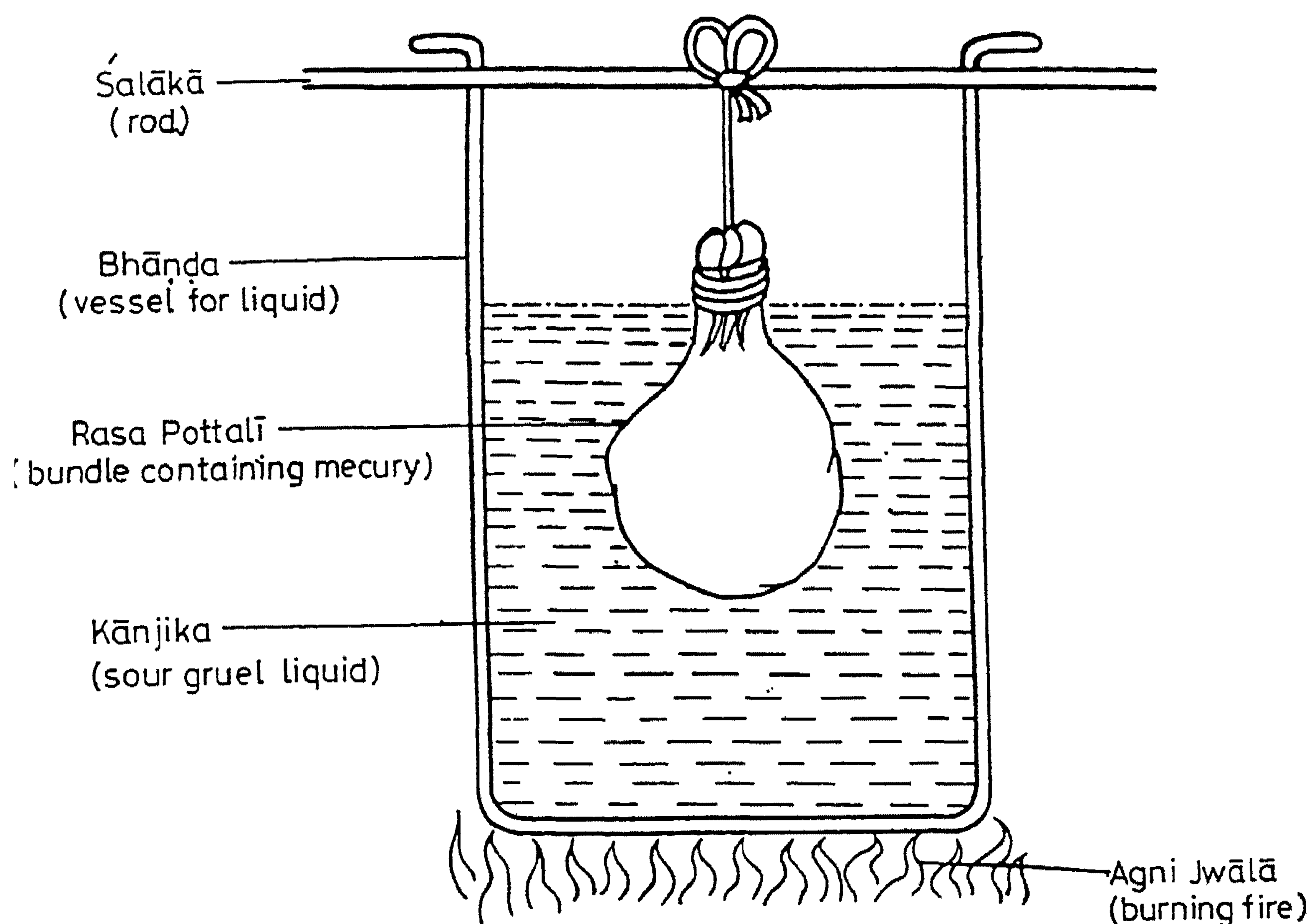


Fig.1 (a) Tāpana, (b) Nirvāpa



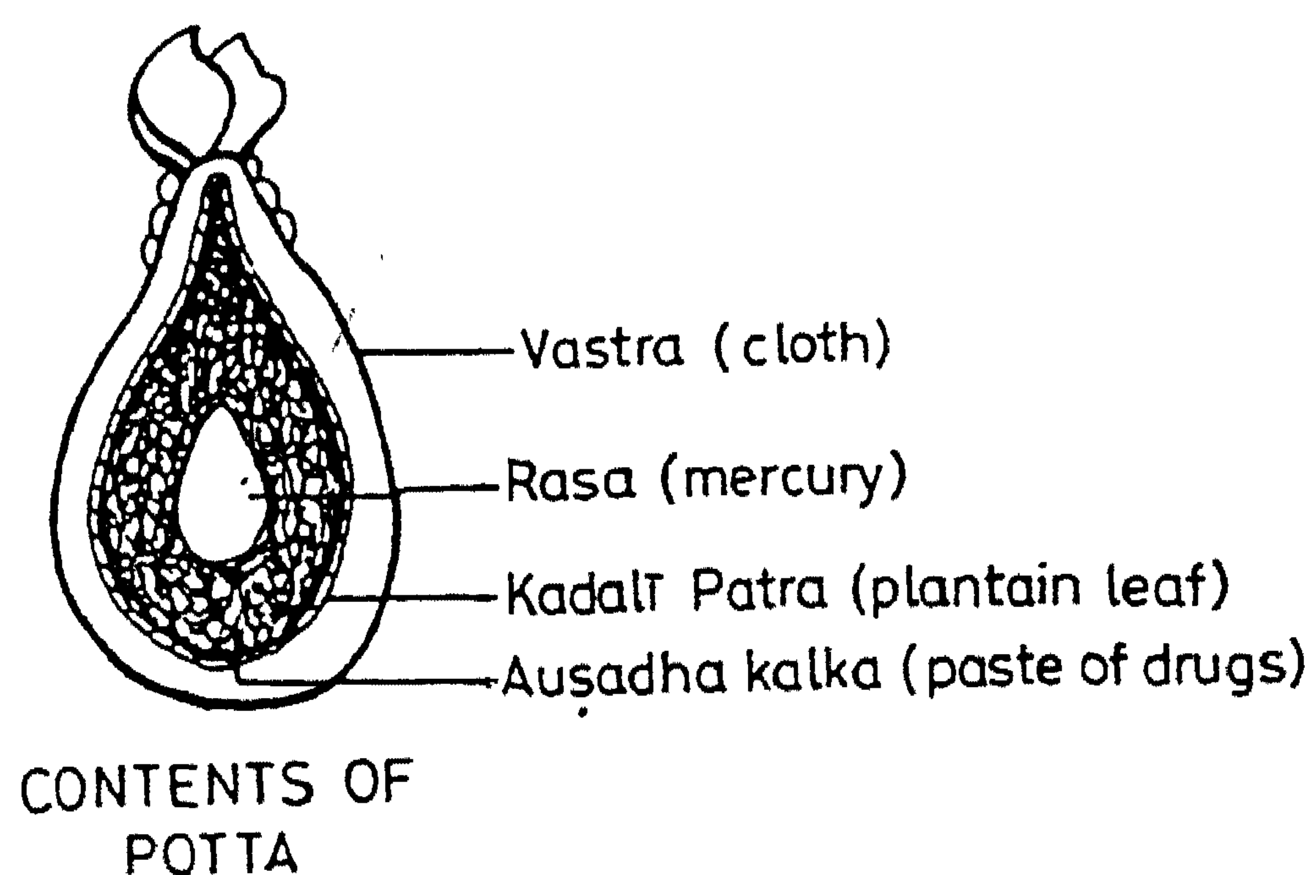


Fig.2 Dola-Yantra

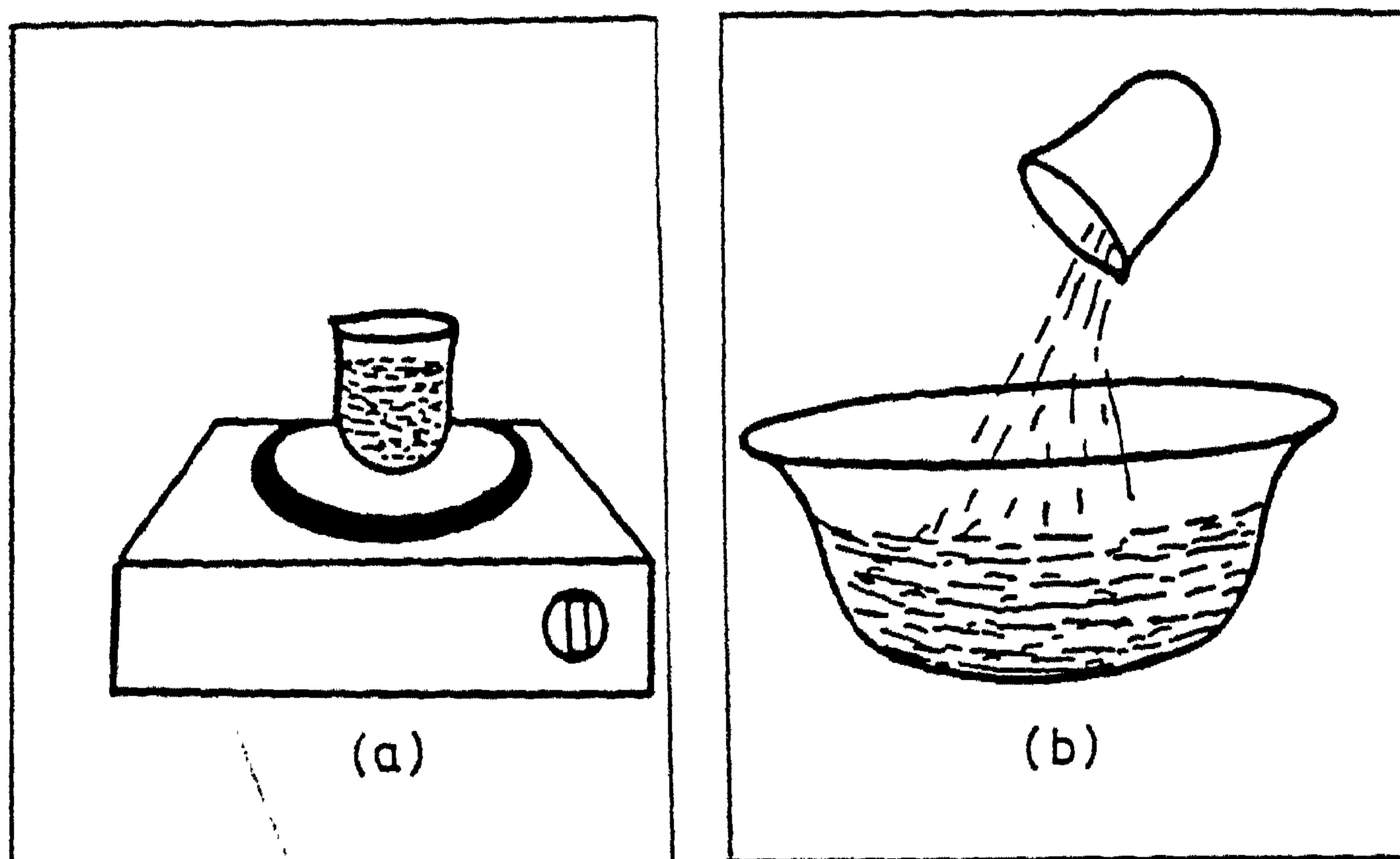


Fig.3 Dravana and Dhalana

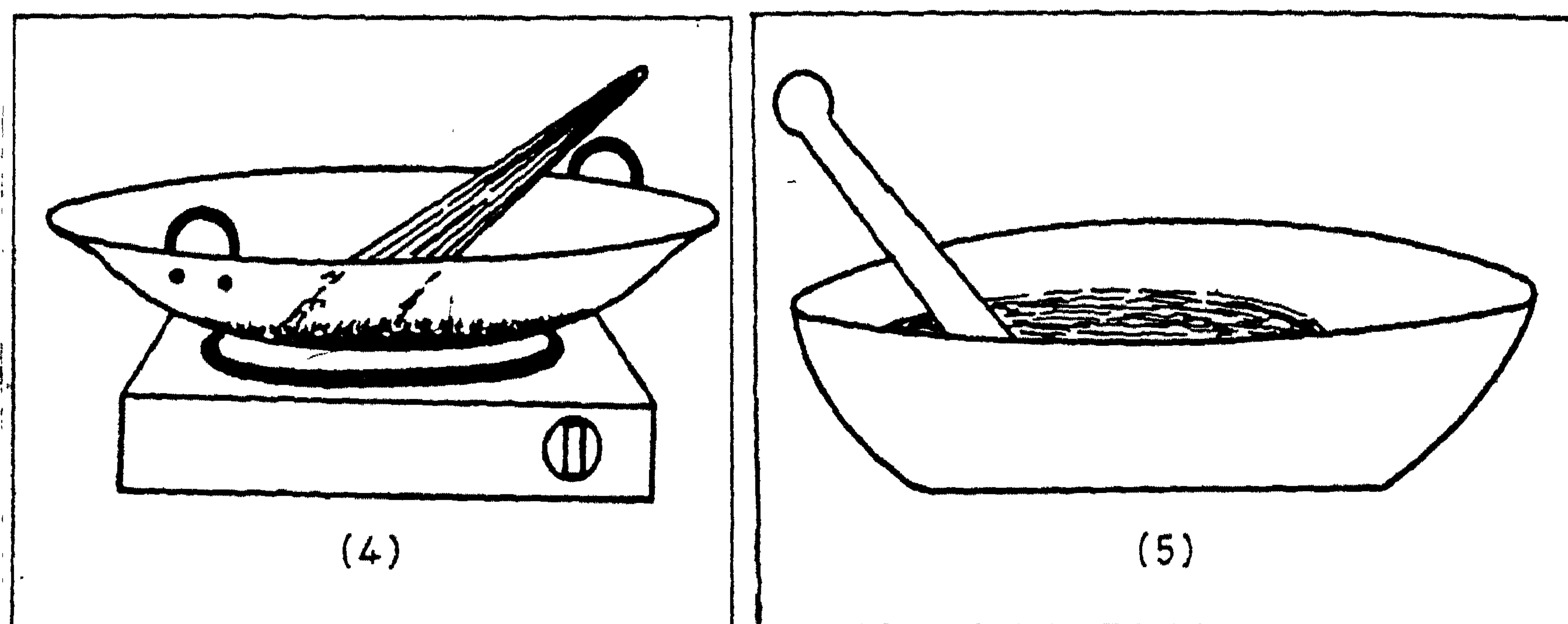


Fig.4 Jāraṇa

Fig.5 Khalava-Yantra

These are some of the procedures to remove the impurities and toxic material from the drugs and to impregnate organic materials to make these organo metallic compounds. Not only the procedures for *Śodhana* are mentioned in this text but the *Śodhanīya* drugs are also mentioned here, the details of *Śodhana* concept are found mentioned in this text. As regards the *Loha Māraṇa* concept a few terms related to this concept are found mentioned in this text such as *Bhāvita* and *Putita* with reference to *Tīkṣṇa loha* and *Mṛta* with reference to *Śulva* (Copper). It indicates the starting of development of *Mārana* concept in this text.

Apart from *Śodhana* and *Māraṇa* processes of metals this text seems to have given more emphasis on *Satvapātana* (Metal extraction) concept. As this text is mainly devoted to describe 18 special processes of Mercury and during these processes *Vaikrānta, Kānta, Sasyaka, Mākṣika* and *Vimala* etc. minerals are recommended to be added with Mercury but these could not be consumed by Mercury in their original form as only the metal content of these minerals could be mixed with Mercury as *Grāsa*, hence many methods for the *Satvapātana* (metal extraction) of these minerals are found mentioned in this text. Moreover while describing the *Satvapātana* methods for various minerals the specific colour of the

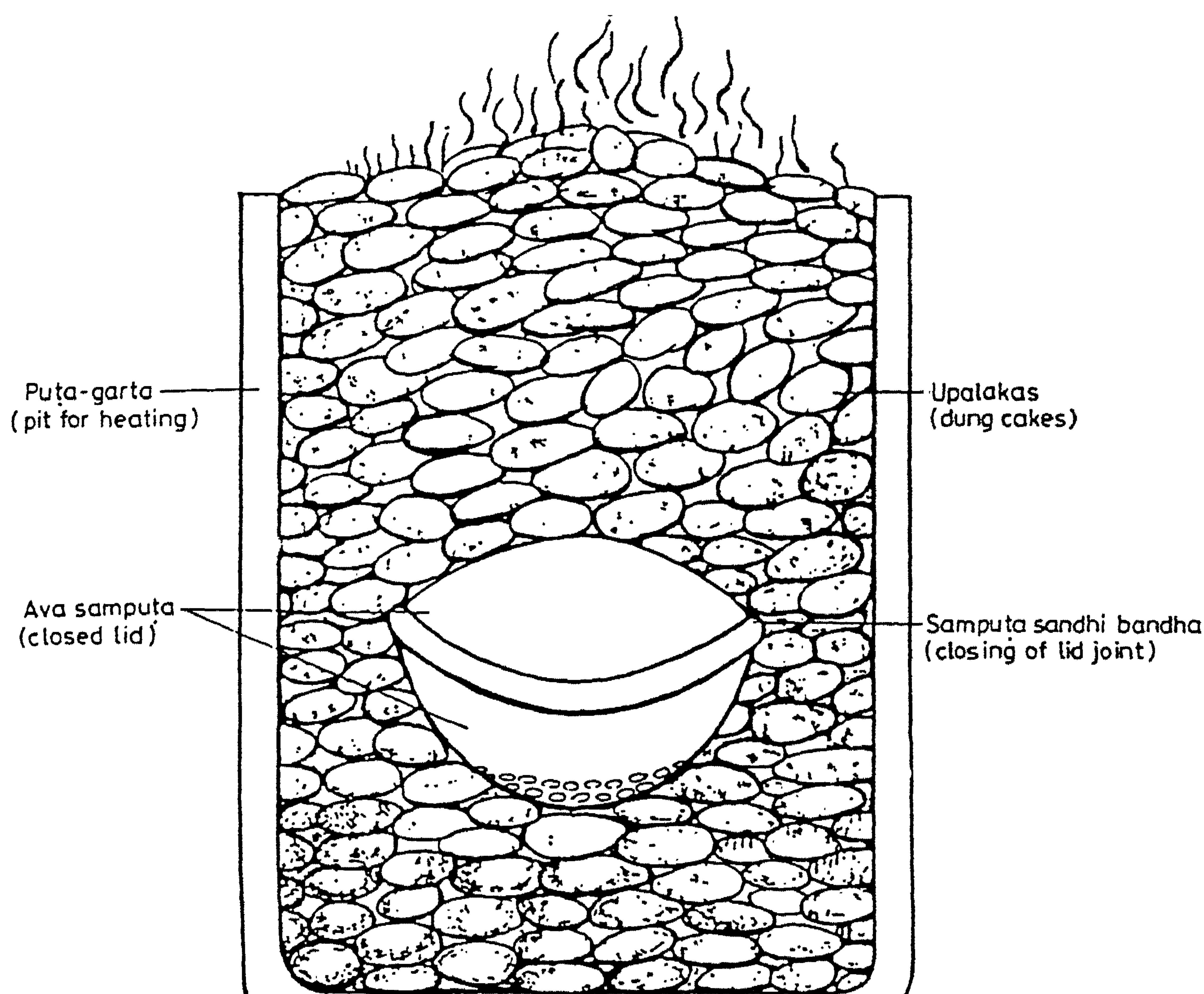


Fig.6 Puṭa-Yantra

particular *Satva* (Metal content) of the particular mineral is also mentioned and on that basis it could be said that the author knew that a particular mineral is a compound of particular metal and that metal could be extracted from the mineral as *Satva.*

2. Rasarnava Tantra (11th century A.D.)

The author of this text is unknown. It is written in the form of conversation between *Devī* (Goddess) and *Bhairava* (Lord Śiva). The probable date of this text is about 11th century A.D. There are 19 (Nineteen) Chapters in this text and these are devoted to deal Mercury, its eighteen *Saṃskāras* and in the end a few mercurial compounds/preparations recommended for internal use. Besides mercurial processes and preparations a few metals and minerals required for being used in mercurial processes are also found described in this text.

Metals and their Classification

In *Rasārṇava* only six metals are described and are divided in three groups, viz.

1. *Sāraloha* - Gold and Silver
2. *Sādhāraṇa* Loha - *Tīkṣṇa* and *Śulva* (Steel iron and Copper)

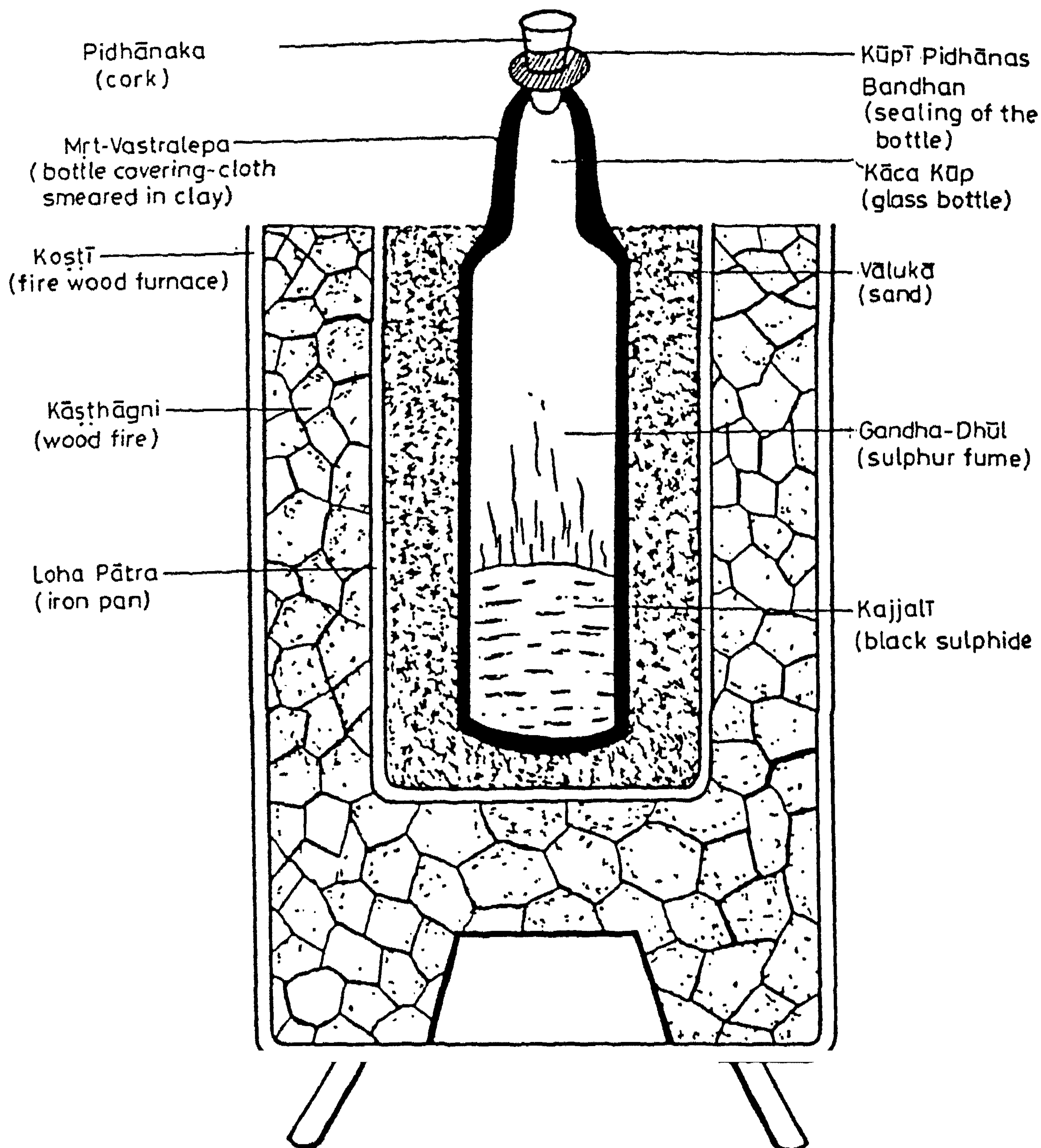


Fig.7 Balukā-Yantra

3. *Pūtiloha* - Lead and Tin

These metals are claimed to be *akṣaya* in preceding order if subjected to heating i.e. lead is lost highest on heating, while there is no loss in Gold on heating. In *Loha* varieties *Kānta* Loha is also found mentioned in this text.

Minerals and their Classification

Besides metals, a few minerals and their groups are also found mentioned in this text, viz.*Abhraka* (Mica),*Vaikrānta* (Turmaline), *Vajra* (Diamond) and *Kānta* (Magnetite) are included in *Śakti* group that means these are used to induce *Śakti* (high potentiation) in Mercury and are described in detail.

In addition to above minerals eight minerals of *Mahārasa* and eight minerals of *uparasa* groups are also found mentioned in this text, viz.

Minerals of Mahārasa group

Mākṣika (Chalcopyrite), *Vimala* (Iron Pyrite), *Śaila/Adrija* (bitumen/Mineral Pitch), *Capala* (Tin mineral), *Rasaka* (Zincite/Zinc Mineral), *Sasyaka* (Copper sulphate mineral), *Darada* (Cinnebar/Mercury mineral) and *Srotoñjana* (Galena/Lead mineral).

These have been included in *Mahārasa* group as these are claimed to be very useful in Mercury processings.

Minerals of Uparasa group

Gandhaka (Sulphur), *Tālaka* (Orpiment), *Śilā* (Realgar), *Saurāṣṭri* (Alum), *Khaga* (Ferrous Sulphate), *Gairika* (Hematite), *Rājāvarta* (Lapis lazuli) and *Kaṅkuṣṭha* (Unidentified mineral).

The *Satvas* (metallic contents) of these minerals are generally used in *Rasa Saṃskāras* (mercurial processes) for *Jāraṇa* and *Rañjana* purposes etc.

Mercurial and Metallic Compounds

1. *Divya Rasāyogas* (*Rṇv.T.* 12/248-251)

   This is a compound of Gold, Mica and Mercury which after certain treatments is advised for internal use to prolong life in men. The urine, stool and sweats of the man who uses this compound develops the power of transforming Copper into Gold.

2. *Daradādi Pārada Yoga* (*Rṇv.T.* 12/318-321)

   It is a compound of Mercury, Orpiment, Realgar, Copper Pyrite, Cinnebar and aconite. It is advised for internal use after certain treatment to make the men free from wrinkles and greying of hairs and also to prolong his life span.

3. *Vyoma Guṭikā* (*Rṇv.T.* 12/346-347)

   It is a compound of Mercury, Mica, *Mākṣika Satva*, Diamond Turmaline and Orpiment. It is advised for internal use mixed with Ghee, Jaggary and Honey to prevent and to cure greying of hairs of a man.

4. *Vaikrāntādi Guṭikā* (*Rṇv.T.* 12/350-351)

   It is a compound of Mercury, Turmaline, Mica, Magnetic Iron and Diamond taken equal to Mercury and *Rājāvarta* ¼ th to Mercury. It is advised for internal use to cure all kinds of diseases and to prevent senile changes.

5. *Amara Sundarī Guṭikā* (*Rṇv.T.* 12/352-353)

   It is a compound of Mercury, Gold, Silver, Copper, Magnetic Iron and Mica. It is advised to be kept in mouth to make the man free from senile changes, wasting diseases and to make him very strong.

6. *Sūta Bhasmādi Guṭikā* (*Rṇv.T.* 12/354-358)

   In this compound Mercury, Kānta Loha and Mākṣika are used in ash form alongwith *Śilājatu*, *Vidaṅga* and *Pathyā*. It is used internally mixed with honey

and ghee contineously for one year to make the consumer very strong and to live long.

It is said further in this text that if Mercury is used in 'bhasma' form it acts as best *rasāyana*, does not produce any toxic effects (complications of Mercury) and known as *Divyauṣadhi.*

7. *Khecari Guṭikā/Sundarī Rasa* (*Rṇv.T.* 12/371)

   It is a compound of Mercury, Gold, Copper and Orpiment. Its bolus should be treated with *Śailavāri* and then be used internally to grant thousand years long life.

8. *Vajrāṅga Sundarī Guṭikā* (*Rṇv.T.* 18/174-177)

   It is a compound of Mercury, Gold, Silver, Iron, Tin, Copper, Mica, Ferrous Sulphate and Diamond. After completing the process it is advised to be kept in mouth to achieve all types of Siddhies (success), to destroy ageing process and death.

9. *Sarva Siddhiprada Rasa* (*Rṇv.T.* 18/178)

   It is a compound of Mercury, Gold, Silver, Copper, Magnetic Iron, Steel Iron, Tin, Lead, Mica Satva and Diamond. It is advised to be kept in mouth to induce sexual vigour, to destroy high temperature and *doṣa sancaya* and to prolong lifes span.

10. *Sarva Siddhidā Guṭikā* (*Rṇv.T.* 18/179-181)

    It is also a compound of Mercury, Gold, Mica Satva, Diamond and *Kānta Loha.* It is also known as *Divya guṭikā* and advised to be kept in mouth to achieve all types of *Siddhies.*

3. Cakradatta (11th AD)

The *Cakradatta* is a most popular and important text on Ayurvedic therapeutics written by Shri '*Cakrāpāṇidatta*' in about 11th century A.D. In this text many processes concerning to Mercury, Metals and minerals and many Mercurial and Metallic compounds are found described alongwith herbal preparations and other Ayurvedic subjects.

A. Mercurial Compounds (prepared with sulphur)

1. *Rasa Parpaṭi* (*CD.* Grahaṇī 85-91)

   It is a compound of Mercury and Sulphur in Sulphide form. To prepare this purified Mercury and Sulphur are advised to be taken. For preparing '*Rasa Parpaṭī*' these are first mixed and made into black powder form (*Kajjalī* form) by trituration (*Fig. 5*), and then made into thin scally (*Parpaṭa* like) form by melting on slow fire and pressing in between Banana leaf.

2. *Tāmra Prayoga* (*CD.* Grahaṇī 92-98)

   It is a compound of Mercury, Sulphur and Copper, prepared by heating through *Bāluka Yāntra* method (*Fig. 7*).

3. *Kṣudhāvati Guṭikā* (*CD.* Amlapitta 40-53)

   It is a compound of Mercury, Sulphur, Mica, Iron and rusted Iron (*Mandura*) and advised for internal use in cases of hyper acidity like conditions.

4. *Rasa Maṇḍūra* (*CD.* Pari-Śula 54-56)

   It is a compound of Mercury, Sulphur and *Maṇḍūra* and prescribed for *Parināma Sūla* (Duodenar ulcer).

Mercurial Compounds (prepared without Sulphur)

5. *Rasa Guṭikā* (*CD.* Arśa 177)

   It is a compound of Mercury and Mica alongwith some herbal drugs and advised for internal use in piles and to stimulate *Agni* (digestive fire).

6. *Sūtagarbha Karañja Bījaprayoga* (*CD.* Vṛṣya 51)

   In this Mercury is first closed inside the *Karañja bīja* which is then wrapped with Gold sheet. It is advised to be kept in mouth at the time of sexual intercourse to retain semen discharge for longer duration.

7. *Pārada Pralepa* (*CD.* Kṛmi 14)

   It is a mercurial paste prepared by mixing Mercury with *Dhattūra* juice or *Tāmbūlapatra* juice and applied externally to destroy *Yūkās* and their cysts in the hairs.

B. ***Metallic Compounds***

Iron compounds in Leha (licking) form :

1. *Agnimukha Loha* (*CD.* Arśa 161-168)

   It is an iron compound containing number of herbal drugs and prepared in the form of *Leha* (licking preparation) and advised for internal use.

2. *Bhallātaka Loha* (*CD.* Arśa 169-176)

   It is also an iron compound containing number of herbal drugs and prepared in leha form for internal use.

   Ayorajādi leha (*CD.* p. 27) *Dārvyādi leha* (*CD.* p. 28), *Dhātrīleha* (*CD.* p. 29) are also iron compounds prepared in *leha* form.

Iron Compounds Prepared with Herbal drugs :

Following Iron compounds, prepared with herbal drugs, are found referred to in this text : *Nāgarādya Cūrṇa* (*CD.* Pāṇḍu 5), *Ayorajaḥ Prayoga* (*CD.* p. 6) *Navāyasa Loha* (*CD.* p.10), *Vidaṅgādya Loha* (*CD.* p. 33-34), *Tikṣṇa Loha Cūrṇa Prayoga* (*CD.* Sula 80), *Loha Cūrṇa* yoga (*CD.* Pari. Śula 13), *Krisṇadi Cūrṇa* (*CD.* Pari. Sula 14-15), *Pathyādi Cūrṇa* (*CD.* Pari.Śula 16), *Sāmudrādi Cūrṇa* (*CD.* Pari.Śula 17-20), *Saptāmṛta Loha* (*CD.* Pari. Sula 23-24), *Triphalā Loha* (*CD.* Pari.Sula 82), *Triphalādya Loha* (*CD.* Pari Śula 57), *Lohaguṭikā* (*CD.* Pari Śula 58-59), *Dhātrī Loha* (*CD.* Pari Sula 60-65), *Lohamṛta* (*CD.* Pari Śula 66-72), *Vidaṅgādya Cūrṇa* (*CD.* Sthaulya 5), *Vidaṅgādya Loha* (*CD.* Sthaulya 6-9) and *Loha rasāyana* (*CD.* Sthaulya 19-29).

Besides these iron compounds there is a reference of '*Amṛta Sāra Loha rasāyana*' in Rasāyanādhikāra of this text in which *loha śodhana vidhi* (method of Iron purification) and *loha māraṇavidhi* (method of Iron incineration), reasons for *loha śodhana* and *trividha loha pākas* (three types iron heating techniques) - such as *bhānupāka* (heating through Sun rays *Fig. 8*), *sthālīpāka* (heating in a wide mouth vessel with triphala decoction *Fig. 9*) and *puṭapāka* (heating by *Puta* system) for converting iron into fine ash form are described in detail.

Iron Compounds prepared with Minerals :

In this group Iron compounds prepared with some minerals like *Maṇḍūra* (an Iron Oxide formed naturally/rusted iron), Mica and Sulphur are described.

1. *Kṣudhāvti Gutikā* (*CD.* Amlapitta 40-53)

   It is a compound of Iron prepared with Mica, *Loha Kiṭṭa/Maṇḍūra* (rusted iron), Mercury and Sulphur.

2. *Dhātrī Loha* (*CD.* Śul. 51-58)

   It is also an iron compound in which mica and iron oxide formed naturally are mixed.

3. *Loha Maṇḍūra Cūrṇa Prayoga* (*CD.* P sul. 13)

   In this Iron powder is mixed with Iron oxide and *Triphalā Cūrṇa* and advised for internal use in *Pariṇāma Śula.*

Compounds of Mandura (Iron Oxide)

Maṇḍūra itself is an Iron compound (Iron oxide) formed naturally if Iron is kept in an open atmosphere for a long duration. Here the chemical reaction (Oxidation) proceeds slowly. It is also a therapeutically useful material hence, a number of Mandura containing compounds are found described in this text.

1. *Maṇḍūra Prayoga* (*CD.* Pāṇḍu 31)

   It is a naturally formed Iron oxide compound processed in such a way that it is converted to a very fine powder form, suitable for internal use. The other compounds of Iron oxide (*Maṇḍūra*) are :-

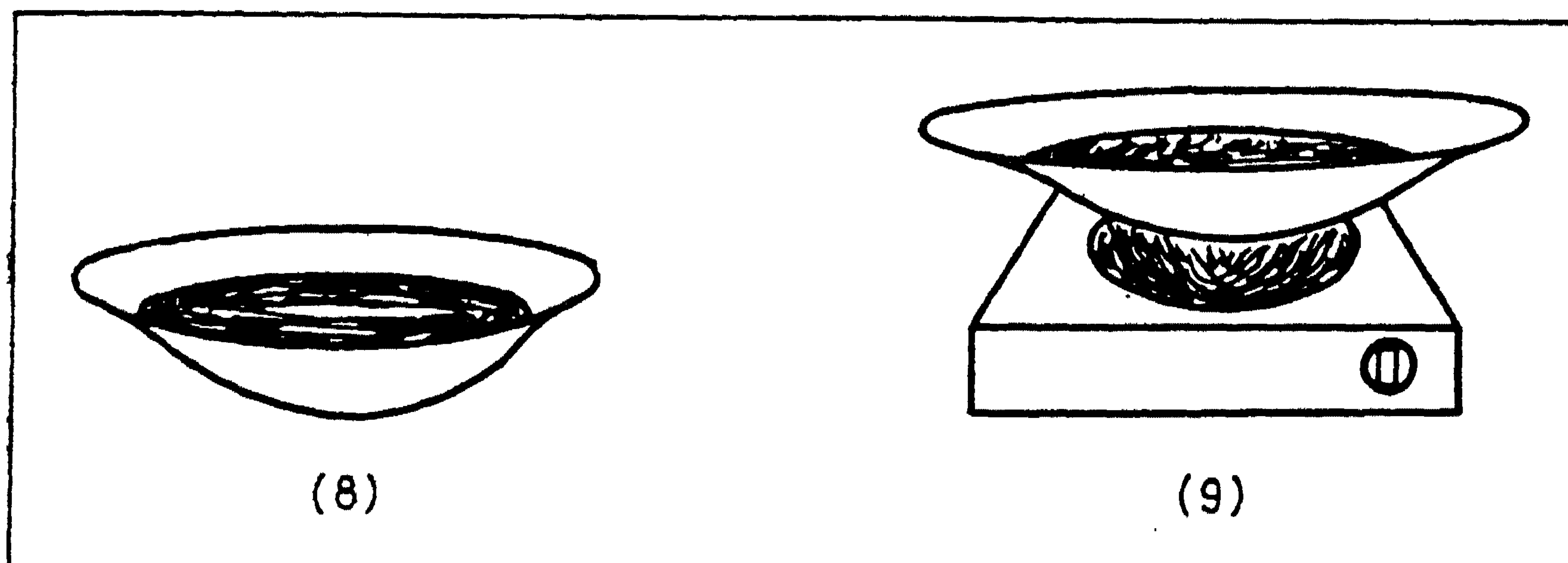


Fig.8 Bhānu-Pāka *Fig.9 Sthālī-Pāka*

Tryūṣaṇādi Maṇḍūra (*CD*. p. 35-40), *Punarnavā Mandūra* (*CD*. p.41- 43), *Vajra Vaṭaka Maṇḍūra* (*CD*. p. 44-48), *Maṇḍūra yoga* (*CD*. Śul. 78), *Dhātrī Loha* (*CD*. Śul. 51-58), *Loha Maṇḍūra Curṇa Prayoga* (*CD*. Su. 13), *Kolādi Maṇḍūra, Bhīma-Vaṭaka Maṇḍūra, Kṣīra-Maṇḍūra, Gavikādi-Maṇḍūra, Śatāvarī-Maṇḍūra, Tārā Maṇḍūra, Rāma-Maṇḍūra, Bṛhacchatāvarī-Maṇḍūra* and *Rasa-Maṇḍūra* (*CD*. p. 27-56),

Kṣudhāvatī Guṭikā (*CD*. Aml. p. 40-53).

Copper Compounds

Besides Mercury and Iron compounds there is a reference of '*Tāmra Rasāyana*' in Rasāyanadhikāra of Cakradatta (126-148). In these two procedures of *Tamra Rasāyana* are described which include copper purification method and incineration methods alongwith their doses, indications and method of uses.

Apart from above the purification process for following drugs have also been found described in *Cakradatta Amlapitta Cikitsā*. In this text purification methods for *Abhraka* (Mica), *Loha* (Iron), *Maṇḍūra* (Iron Oxide), *Rasa* (Mercury) and *Gandhaka* (Sulphur) are described.

Thus, it may be said that during the time of Cakradatta (11th AD) the *Śodhana* and *Māraṇa* methods for Mercury and a few metals and minerals have been developed. In metals Iron, Copper and *Maṇḍūra* Compounds are mainly referred to in this text.

4. *Rasendra Cūḍāmaṇi* (12th A.D.)

Rasendra Cūḍāmaṇi is an important text of Alchemy and therapeutics written by Sri Somadeva in about 12th century A.D. This text seems to be more systematic and well classified and covers almost all the aspects of Ayurvedic Pharmaceutics specially concerning to Mercury, Metals and Minerals.

It is important to mention here that in this text though Mercury and its processes are described in detail the mercurial compounds of therapeutic importance are not found described. In this text '*Jāraṇa*' process of Mercury is given more importance and the method for '*Abhraka Satva Jāraṇa*' in different proportion alongwith their properties and *Tāmra Jāraṇa, Loha Jāraṇa* and *Suvarṇa Jāraṇa* methods are also found described. but, there is no mention of '*Mūrcchanā*' process in this text which is important from the point of view of preparation of mercurial commpounds of curative value.

As regards the metals, minerals, their processing and compound preparation this text for the first time devoted three chapters completely and exclusively.

In this text nine metals have been described as *lohas* and have been classified in three groups, viz.

1. *Śuddha Loha* 2. *Pūti Loha* and 3. *Miśra Loha*

Metallic Compounds

1. *Soma Nāthī Tāmra*

   It is a compound of Copper, Mercury, Sulphur, Orpiment and Realgar and prepared in a *Kupi* (Bottle) through *Balūkā yantra* system of heating. Its dose is 4-6 ratti (500-750 mg).

   It is a method of preparing *Tamra bhasma* (Copper Sulphide).

2. *Soma Devodita Tāmra bhasma Yoga*

   It is a compound of Copper prepared in *bhasma* form with Mercury, Sulphur and a few Herbal drugs. Its dose is 2 *ratti* mixed with *Pippalī* and ghee.

3. *Amṛta Loham* :

   It is an Iron compound prepared in *bhasma form* from *Kāla Loha* or *Kānta loha* with Sulphur, *Matsyākṣi* and Milk.

4. *Rajata Rasāyana*

   It is a compound of Silver, Copper and Mica alongwith *Trikatu* equal to all. It should be used mixed with Ghee and honey.

5. *Kānta Rasāyana*

   It is a compound of *Kanta Loha* (magnetic iron), and *bhasma* mixed with Abhraka Satva, Gold, Copper, *Vaikrānta* and *Raupya Mākṣika.*

6. *Vaṅga Rasāyana*

   It is a compound of *Vaṅga bhasma* (tin oxide) mixed with *Kānta Loha bhasma, Abhraka bhasma* and *Rājāvarta bhasma.*

7. *Śīśā Rasāyana*

   It is a compound of lead in which lead *bhasma* is mixed with *Mākṣika bhasma,* Copper *bhasma,* Silver *bhasma, Kānta Satva bhasma, Abhra Satva bhasma* and *Sphaṭikā bhasma* and processed as per direction.

8. *Pittala Rasāyana*

   It is a compound brass *bhasma* mixed with *Kānta bhasma* and *Abhra Satva bhasma* and with some herbal drugs.

Besides these metallic compounds the processing methods i.e. *Śodhana* (purification) and *Māraṇa* (Incineration) of each metal referred to in this text are also found described in this text here. These processes are employed to convert the metals into some compound form by way of some chemical reactions taking place during processing. Thus since the beginning of 12th century A.D nine substances included under *Loha* (Metal) group are processed in such a way that these either change into Oxide, Sulphide, Sulphate form or into very fine state of subdivisions and thus making these readily absorbable into the system.

These processes also help to make these preprations less or even non toxic to the human system on internal use.

It is also important to mention here that for *Śodhana* and *Māraṇa* of each metal, number of methods are found described in this text which may sometimes help to convert the metals into different compounds on the basis of the drugs used in the process.

In the beginning of the 14th Chapter, a few fundamental principle for *Loha Māraṇa* are also found mentioned in this text, such as *Loha Māraṇa* with *Rasa Bhasma* or Mercurial compounds is considered best, with herbal drugs medium, with sulphur etc. minerals inferior and with *Arilohas* (anti metals) most undesirable as it may induce undesired properties in the *bhasmas*.

Another important point mentioned in this text is about the use of the term '*Bhasma*' in the context of metals and minerals i.e. this text for the first time used the term *bhasma* for *Mṛta Loha* frequently.

Apart from above, this text has also mentioned the heating systems and the heating schedules required to prepare *bhasma* of different metals. The number of heatings required for each metallic *bhasma* are found specified in this text.

The specific colour of the finished product (*bhasma*) of each metal is also found mentioned indicating the relationship between the type of compound prepared in the particular metal with particular processing method.

Further, it is also mentioned in this context that for preparing the *bhasma* of particular metal particular type of *puta* (heating temperature pattern) is required for getting optimum chemical reaction to prepare a desired compound of the metal. In addition to above following minerals and Gem stones are also found described and advised to be subjected to *Śodhana* and/or *Māraṇa* processes to convert these into desired compounds in which these prove beneficial/effective to the system and become least or non toxic.

In Minerals : Mica, Lapis Lazuli, Tourmaline, Copper Sulphate, Iron pyrite, Bitumen/Mineral Pitch, Zincite, Chalcopyrite, Sulphur, Orpiment, Alum, Realgar, Galena, *Kankuṣṭha* (Unidentified mineral), Green Vitriol, Hematite, Arsenic, Ammonium Chloride, Cowry, Amber, Red Oxide of Mercury, Cinnabar and litharge are described.

In Gem Stones : Ruby, Pearl, Coral, Emerald, Topaz, Diamond, Sapphire, Hessonite/Cinnaman Stone, Cat's eye. These are either treated with *Śodhana* and/or *Marana* process for converting these into desired compounds.

Further, in the beginning of this text descriptions regarding pharmacy, its staff and equipments, alongwith definitions of various technical terms, apparatus', crucibles, heating systems, schedules and different kinds of furnaces and various groups of herbal and mineral drugs are also found mentioned.

5. *Rasa Prakāśa Sudhākara* (12th century A.D.)

It is another important text of Indian Alchemy and therapeutics. It has been written in the later part of 12th century A.D. by Shri Yaśodhara bhaṭṭa. It contains 13th Chapters which are devoted to describe Mercury, its compounds, 9 metals, their types, properties and processing techniques, 20 minerals, Nine Gems, 103 metallic and mineral compounds and artificial preparation of Gems and Metals.

In this text many details regarding Mercury such as its *Doṣas* (impurities), *Saṃskāras* (18 special processes for removing its various types of impurities and potentiating it in many ways specially for making it suitable for internal use) are found described.

As regards mercurial compounds the four types of *Pārada bandhas* either on the basis of forms (i.e. *Jalūkā, Khoṭa, Poṭa* and *Bhasma*) or on the basis of the types of drugs used i.e. *Mūlikā* (herbs), *Maṇi* (Gems), *Dhātu* (Metals) and *Druti* (liquified metals) are found mentioned. It is also mentioned in this text that for making *Pārada Bhasma* the Mercury extracted from *Hiṅgula* (Cinnabar) should be used as Mercury obtained from this mineral was considered to be free from impurities and superior in properties. From this *Pārada* three coloured *bhasmas* are described to be prepared i.e. Red, Black and White.

The Red and Black coloured *pārada bhasmas* are the Red and Black sulphides of Mercury while white coloured *pārada bhasma* may be Mercuric Mercurous chloride.

In case of other types of *Pārada bandhas* it may be said that these may be the metallic amalgams of Mercury.

In metals Gold, Silver, Copper, Iron, Tin, Lead are the pure metals and Bell metal, Brass and *Varta Loha* (German Silver) are the metallic alloys which when treated with *Śodhana* and *Māraṇa* treatments may forms some metallic compounds depending upon the methods and drugs used during these treatments i.e. either in oxide or sulphide or in mixed compound form except Gold which is made to reduce to finest form only.

In minerals Mica is Ferromagnesium aluminium silicate compound which when treated with *māraṇa* treatment may convert into an Iron and Aluminium oxide. Chalcopyrite may convert into Copper and Iron Sulphide, Zincite into Zinc oxide, Copper Sulphate into Copper Sulphide, Ferrous Sulphate into Ferric oxide and Calcium Carbonate into Calcium oxide etc. compounds. Many minerals are used only after their purification treatments which means these are used in their original form and compounds. As in their case probably no change in their compound is considered necessary to achieve their therapeutic effectiveness.

Further in VIIIth Chapter author himself has mentioned 103 formulations which are herbomineral compounds or organo metallic compounds and these are recommended for being used internally for the treatment of respective diseases as therapeutic agents.

Besides processing of minerals for therapeutic uses the minerals are used for extracting their *satvas* (Metal contents). And so extracted metals are also advised to be treated with respective *Śodhana* and *Māraṇa* treatments to convert these into suitable metallic compounds for therapeutic uses.

It is also mentioned in these texts that the metals obtained as *satvas* are many times superior in their therapeutic effectiveness than the native metals (metals obtained from nature in natural form).

The text has also mentioned the artificial preparation methods for a few gems and metals. That means in ancient times probably many metals could not be obtained in sufficient quantities in nature and this might have made them to think for some alternative sources to obtain metals and minerals and as a result artificial gem making and metal making methods were evolved.

6. *Rasendra Cintāmaṇi* (12th century A.D.)

This text is written by Shri Ḍhuṇḍhuka Nātha in the later part of 12th century A.D. The Indian alchemy and therapeutics are dealt with in this text. It includes a few important manufacturing processes, mercurial and metallic compounds.

In mercurial processes 19(nineteen) *saṃskāras* (special processes) for removing various types of mercurial *doṣas* (impurities/toxic materials) and for inducing many alchemical and therapeutic properties in Mercury are described.

Besides special processes of Mercury a most important process known as *Mūrcchanā* (compound making) for preparing mercurial compounds of therapeutic importance is described for the first time in this text. This text gives much emphasis on *Mūrcchanā* as according to it this is the only process which induces a definite disease destroying capacity in mercurial compounds.

It is further said in the context of *Mūrcchanā* that before subjecting Mercury with this process prior purification of Mercury is essential. Many kinds of *Mūrcchanā* are described in this text and of these following two types are most important from therapeutic point of view, viz. 1. *Mūrcchanā* with Sulphur and 2. *Mūrcchanā* without Sulphur.

Further in the context of *Mūrcchanā* with Sulphur it is said that without doing '*Ṣaḍguṇabali jāraṇa*' (without burning six times Sulphur with Mercury) the desired disease destroying power could never be induced in Mercury. It is also mentioned in this text that for inducing Rasayana property consumption and digestion of Mica (*Satva*) and Gold into Mercury is highly essential. Hence, in relation to Mercury *Mūrcchanā* and *Jāraṇa* are the two most important processes to potentiate Mercury for therapeutic as well as Rasāyana purposes.

The methods and the apparatus' required for burning six times sulphur are also described in this text, viz.

1. As regards the method the Sulphur should either be added at a time or gradually and the heat should be applied through *Sikatā yantra* Bātuka system in a graded (slowly increasing) manner with a view to allow sulphur to remain in contact with mercury for longer duration.

2. As regards the apparatus the *Sikatā* and *Bhūdhara yantras* are specially recommended. Thus, for '*Ṣaḍguṇa Gandhaka Jāraṇa*' the *Kūpīpāka* method is usually followed. The descriptions regarding the *Kūpī* (bottle) and its sealing materials are also found mentioned in this context.

Besides '*Ṣaḍguṇa Balijārana*'. The preparation method for preparing *Kajjalī* is also mentioned in this context.

Further, in the context of '*Mūrcchanā* without Sulphur' this text has mentioned about '*Lavana Mūrcchanā*' i.e. compounding of Mercury with *lavaṇa* (Sodium Chloride) and the compound thus prepared is known as '*Rasa lavaṇa Piṇḍa*'. It is also claimed as one of the type of *bandhas* (solidified state) of mercury.

It may be mentioned here that though, the term '*Rasa Karpura*' is not found mentioned in this text the terms '*lavana mūrcchanā*' and '*rasa lavaṇa piṇḍa*' and its preparation method (heating in *Kūpī* through *Sikatā yantra*) indicate that the

mercurial or mercurous compound known as mercurric chloride was known and prepared in India since the later part of 12th century A.D.

It is also mentioned in this context that if pure Mercury is not available then use *Hiṅgula* (Cinnabar) an important of ore of Mercury for obtaining pure Mercury through Damuru Yantra by extraction method.

Thus, in short it could be said that this text has mentioned the *Mūrcchanā* process for the first time to preparre Mercurial commpounds of therapeutic importance. Two types are usually recommended in therapeutics for curing various diseases, viz.

1. The compounds of Mercury prepared with Sulphur. Its examples are *Kajjalī* and *Rasa Sindūra*.

2. Non Sulphur compounds i.e. compounds of mercury prepared with herbs and *lavana*.

For preparing *Kupipakva Rasāyanas* and/or *Ṣaḍguṇa balijāraṇa* heating through *Sikatāyāntra* in a graded manner is advised to achieve optimum properties and benefits. If pure Mercury is not available its important mineral *hingula* was used for obtaining (extracting) pure Mercury to prepare mercurial compounds with sulphur or *lavana* by *Mūrcchanā* process.

It is claimed that for inducing curative power in Mercury, *Ṣaḍguṇa Balijāraṇa* is essential and for inducing *Rasāyana* property *Jāraṇa* of Mica (*Satva*) and Gold is essential.

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Cosmetics and Perfumes

R.T.VYAS

In ancient India cosmetic was limited to the use of *sṛk*, flower-garlands and *gandha*, sandal-paste to beautify the persons of gods and men (*RV*.IV.38.6; *AV*.I.14.1., and *Śat.Br.* XIII.5.4.2). The word *sugandhi*, well-perfumed is used twice in the Ṛgveda in connection with Agni and Rudra who is also a form of Agni. In Ṛgveda (VIII.19.24) Agni is described as carrying *havyāni* or oblations to different gods through his well-scented mouth - *āsā sugandhinā*. In Ṛgveda (VII. 59.12) Rudra is prayed to deliver one from death and bestow immortality. In this *mantra* Rudra is given an epithet, *sugandhim* or well-perfumed, which Western scholars like Griffith, Wilson and others translate, following Sayana, as "of widespread fame". But as is clear from the earlier *mantra*, Rudra, that is Agni, is said to have "scented mouth" that is to say "scented flames". In the present context mouth of Agni stands for its flames. Agni, as carrier of oblations of melted butter, cooked rice, barley cakes and other perfumed articles, must necessarily emit scented smoke. Thus its epithet *sugandhim*, well- perfumed, appears most appropriate. Moreover, in the *Khila-* portion of the *Ṛgveda*, *Śrīḥ*, the goddess of wealth is qualified as *gandhadvārām* or "having the gates of scented wood". This indicates that in Vedic times, the kings and rich men possibly used to have the doors of their palatial mansions, made from sandal wood and the like.

Similar expressions involving the use of the word *gandha* are also found in *Taittirīya Saṃhitā* (I.2.6.1, IV. 6.8.4) *Maitrāyaṇī Saṃhitā (II, 5.2., III. 16-1, IV. 2.13) and* Taittirīya Araṇyaka *(X.1.10). In Śatapatha Brāhmana*, the term *gandha* is used for about twelve times. The use of perfumes for anointment and for bath in the post-Vedic times is ascertained by the words, *sugandhaliptaḥ* and *sugandha-snānaśilāḥ*, mentioned in *Viṣṇu Dharmasūtra* (XCIX.19), and *Gautama Dharmasūtra* (IX.2) respectively. Moreover, the word *sugandhi-tejana* occurs at *Baudhāyanaśrautasūtra* (IV.1.2., 3.14), *Vaikhānasaśrautasūtra*, (XI.10.8). Saunaka's *Bṛhaddevatā*, (VII.77,78), states that while Agni was officiating as *hoṭr*, his bones became the *devadāru* tree, his fat and flesh *guggulu* and his sinew became *sugandhitejana* which Macdonell translates as fragrant *tejana* grass (Macdonell 1904, p.271).

Rāmāyana (Critical Edition G.O.S. Baroda) mentions *gandha* (IV.24.16; VII 26.6) *candanāgurugandhi* (II.82.6), *candanodaka-saṃsiktā* (II.74.13), *candanāguruniryāsa* (II.70.16). The word *gandhamālya* is used for eight times and *candana* for more than twenty times. These references indicate that in the age of Rāmāyaṇa, perfumed waters and scented oils were not only used for anointment, but were also used for rendering palaces and public places fragrant. The reference to *gandhataila* (Rāmāyaṇa V.16.18), scented oil, evinces, that the technique of transmission of fragrance of flowers into oil was known in the Rāmāyaṇa age.

Pāṇinī (600 B.C.) in his *Aṣṭādhyāyī* (V.4.135) lays down a rule that the term *gandha* will be suffixed with "i" if preceded by the words *surabhi* and *pūti* and the prefixes *su* and *ut*.

During the age of the Buddha and later, the use of cosmetics developed to a considerable extent as indicated by a great variety of items used for dressing and by the mention of sixty-four arts. Nevertheless, the popular method consisted of wearing flower-garlands, anointment and putting on ornaments, as indicated by the following expression found in *Khuddaka Nikāya* (Smith 1915,p.37).[1]

Brahmajala Sutta mentions the following items used in dressing — *ucchadana*, anointing the person with scents, *parimardana*, rubbing or shampooing, *nahāpana*, bathing, cleansing, *saṃvāhana*, massaging, rubbing, *ādarśa*, use of *mirror*, *anjana* applying collyrium to eyes, *mālāvilepana*, applying sandal paste and wearing garland, *mukhacuṇṇaka*, use of scented powder for face and body, *mukhalepana*, anointing of face, *hattabandha*, wearing bracelet, *śikhābandha*, combing or hair-dressing, *dandaka*, using stick for a walk, *nalikā*, use of small hollow stick, *khagga*, carrying sword, *chatta* use of umbrella, *chitrupanaha* using stylish foot-wear, *uṇhīsa*, wearing a turban, *maṇi*, wearing of gems, *valavijani*, carrying a fan or chowry and *odātāni Vaṭṭham dīghadaśāni*, putting on embroidered and gaudy garments. *Lalitavistāra* (ed. by Lefmann, p. 156), mentions *gandhayukti*, "the art of blending perfumes", among sixty-four arts. There is a similar list in *Kādambarī*, (M.R. Kale's edition, p.125). shorter lists are also found in *Daśakumāracarita* (Buhler's edition, p.12) *Divyāvadāna*(58.100.391). There is a similar list in the *Kāmasūtra* (I.3) where *gandhyukti* is significantly preceded by *Karnapatra bhaṅga*.

Mṛcchakaṭikā (*VIII*. 5.13) mentions gandha-jutti, by the use of which the king's brother claims to have sweet voice.

The *Mahābhārata* mentions (MB.XIV. 49.42) ten varieties of *gandha*, viz. *iṣṭa* agreeable or beneficent, as of musk etc. *aniṣṭa*, disagreeable or harmful, of corpse etc., *madhura*, sweet as from *madhuka* flowers and other sweet-smelling flowers, *katu*, bitter as from peper etc., *nirhārī*, speading by nature, as of assafoetida etc., *saṃhata*, combination of various *compounds*, *snigdha*, as emitted from heated butter and other edible oils, *rukṣa* pungent as of mustard and such other oils, *viśada*, gratifying as of boiled *śālī* variety of rice etc., *amla*, sour as emitted by hogplum and similar sour fruits (*See* BORI ed. Vol.IV 1975 p.2805)

The *Mahābhārata* also mentions three varieties of *dhūpa*, incense, namely (a) *niryasa*, aromatic resin exudation from trees, such as guggulu *Gommiphora rox-burghii* and *sallakī*, *Boswellia serrata* which are dear to gods, (b) *sarala* (so

called perhaps, because it is the earliest of all) produced by burning the leaves of the trees like *sarala, oleo-resin, aguru, Aguilaria agallocha, sallakī, sarjai, Shorea robusta* and others which is dear to the Yakṣas, Rākṣasas and Daityas and (c) *kṛtrima*, artificial, that is made from fermented substances like molasses and the like which is dear to gods, Dānavas, Bhūtas and men. (MB. XIII. 37-43; *see also* Nadkarni, 1954; Bhatt, 1982).

The aforegoing discussion shows that in the initial stages of Indian civilization the terms for perfumes and cosmetics and their use, in vogue, namely *gandha, sugandhi, candan, aguru, sugandhi-tejana, gandhamālya, avasikta, lipta* and *others*, suggest the fact that the art was simple insofar as only the use of scented-water, oil and pastes for anointing and flower-garlands for decorating the person is ascertained. The later Vedic age, covering the Buddhistic era, represents greater sophistication in the use of cosmetics as the related terminology includes a great variety of items and their uses. Majumdar opines, in this regard, that ancient India made sufficient advance so far as this aspect of civilization is concerned. Among the constituents of toilet we have principally to note various fragrant substances, hair-dye, flower-garlands, incense, perfumes, scented oil, collyrium, *anulepana*, (sandal paste etc. for the body) *alaktaka* (lac-dye for the feet) etc. (Majundar 1938, p.85)

The term *gandhayukti* used in works of this period is the most remarkable one, because it indicates the development of a definite technique of preparing and blending of perfumes. It assumes a signal importance as the key-word in the said technique in the following age comprising of the beginnings of Christian era and the subsequent times, as will be made clear shortly.

The *Suśrutasaṃhitā* (1000 B.C. according to Hessler) deals with *anāgatābādhapratiṣedhaḥ*, measures for prevention of diseases yet to arise, and delineates a daily routine of intelligent men, as a major preventive step (Acharya 1945, pp. 589-591):-

1. *dantapavanam*, tooth-cleansing,
2. *mukhanetraprakṣālanam*, washing mouth and eyes,
3. *añjanam*, applying collyrium to eyes,
4. *tāmbūlapatram*, chewing betel-leaf,
5. *śiro (bhyaṅgah)* use of oil for head,
6. *keśaprasādhanam*, combing the hair,
7. *abhyaṅgaḥ*, oil-bath,
8. *pariṣekaḥ*, vapour-bath,
9. *vyāyāmaḥ*, exercise,
10. *udvartanam*, use of scented oil,
11. *utsādanam*, pressing the body at joints,
12. *udgharṣaṇam*, rubbing the body with *iṣṭikā* or smooth stone,
13. *snānam*, taking bath,
14. *anulepanam*, applying sandal paste,

15. *sumanombararatnādharaṇam*, wearing flowers, garments and gems

16. *ālepaḥ*, smearing face with scented paste or powder,

17. *pādābhyaṅgaḥ*, rubbing of soles with butter-oil,

18. *keśanakharomapramarjanam*, removal of hair, and nail,

19. *bāṇavāram*, wearing an armour,

20. *uṣṇīṣam*, wearing of turban.

21. *chatram*, use of umbrella

22. *daṇḍa*, carrying a walking stick,

23. *bālavyajanam*, fanning with chowries,

24. *saṃvāhanam*, massaging the body,

25. *kale nidrāsevanam*, sleeping for regular hours

Pañcatantra (200 B.C.according to Hertel, I.13) mentions a very interesting verse praising the trade of *gandha* as being the best of all,[2] "Of all trades, that of *gāndhika* is the best; what is the use of trades of gold and other things? Here what is bought with one, is sold for a hundred".

The commentator (Shastri 1932, pp,15-17) explaining the word *gāndhika*, states,[3] "One who deals in frarant substances(like scents and perfumes) is called *gāndhika*".

This evidence shows, on one hand, that in India before the Christian era, the trade of scents and perfumes had acquired pre- eminence in that field, which, on the other, presupposes the manufacture of great many items of cosmetics and perfumery on large scale.

Nāvanītakam (200 A.D.,II.10. 1-27) describes the recipes for rendering the hair dark. The tenth chapter since it deals with this topic alone,is entitled, *keśarāgaḥ* (Singh 1925, pp.101,103).

The *Amarakoṣa* (100 B.C. VI. 121-139) gives an interesting list of the items of cosmetics in the section entitled *aṅgasaṃskāraḥ* or beautification of person:- *mārṣṭi*, clean wash, *udvartana* and *utsādana*, anointing with perfumes and rubbing the body, *āplavaḥ*, bath, *carcā* or *sthāsaka*, applying sandal - paste artistically, *patralekhā* or *viśeṣaka*, painting of temples and breasts with saffron, *lohitacandanam*, red sandal-paste, *lākṣā*, lac for the feet, *lavaṅga* and *kaleyaka*, use of clove and *agallochum*, *kolakam*, and *kakkolakam*, *kastūrī*, use of incense and musk-like fragrant substances, *cūrṇam vāsayogaḥ*, perfumed powders for cloths, *gandhamālya*, use of scent and flower-garlands, and *paṭavāsakaḥ*, toilet powder for the face and body.

Varahamihira's *Brhatsamhita* (500 A.D., XV.12 and XVI.18) mentions the word *gandhayukti*, "blending of perfumes", as one of the arts in which persons born under the constellation *citra* and under planet *Budha* are skilled (Bhatt 1982, Part.1, pp.187,196).

The seventy-seventh chapter of the *Bṛhatsaṃhitā* which has in all thirty-seven verses is entitled *gandhayukti*. It prescribes recipes for blackening hair, scented water fit for washing king's head, varieties of scented oil, incense, toilet powder, a

great number of combinations of perfumes, scented tooth-sticks and betel-leaves with areca-nut (Bhatt 1982, Part.II, pp 704-718).

The sixty-fourth chapter of the *Viṣṇudharmottara Purāṇa* (450-650 A.D.), second *khaṇḍa* (vs. 19-42) is also entitled, "*gandhayukti*". There are in all forty-six verses dealing with this topic. Though the term *gandhayukti*, as pointed out earlier, is used in the Buddhist works and also formed one of the sixty- four arts, it is for the first time in the history of perfumery in India that we learn about its actual process in this Purāṇa. This process consisted of eight phases, namely, *śodhanam*, purification, *vāsanam*, scenting with the perfumes of flowers, *virecanam*, process of cleansing, *bhāvanā*, saturation of powder in fluid, *pākaḥ*, ripening by decoction, *bodhanam*, revival of scents with certain reviving agents, *dhūpanam*, fumigating with perfumed vapours and *vedhanam*, further process of revival. These eight steps, called *karmāṣṭakam*, are, then, explained. This is followed by the technique of preparing different kinds of incenses, perfumed water for bath, scented oil, *mukhavāsa* and scented tooth-sticks (Shastri c. 1985, pp.220-221).

Agnipurāṇa (900 A.D.) in a chaper called *rājadhamāḥ* (*strīra-kṣādikāmaśāstram*), deals with the same topic in almost similar style and language, using the same technical terms. The first two processes are at variances, inasmuch as they are called *śaucam and ācamanam*, which seem to be wrongly used in the context of preparation of perfumes (*Ag. Pu.* Ch.224, vs. 19-42)

Kālikā Purāṇa (1050 A.D.) mentions five varieties of *gandha*, nine kinds of *dhupa* and six varieties of collyrium. These are the five types of *gandha*.[4]

"*Gandha* is of five types - powder of fragrant substances, obtained by rubbing, obtained by burning, resin exuded by trees and extracted from the bodies of animals (Shastri 1972, p.513).

The nine varieties of incenses[5] are:

"These are the incenses that can be combined with one another: *Yakṣadhūpa*, *vṛkṣadhūpa*, *śrīpiṣṭa*, *aguru*, *jharjhara*, *patrivāha*, *piṇḍadhūpa*, *sugola* and *kaṇṭha*. (Sastri 1972, p. 520)

The six kinds of collyrium[6] are:

"Listen to that collyrium by which the goddesses Kāmākhyā, Tripurā and Vaiṣṇavī are propitiated: *śauvīram*, *yāmunam*, *tuttham*, *mayūrayāmumam*, *durvikā* and *meghanīlam*. These are the six kinds of collyrium". (Sastri 1972, p. 520)

A significant verse states that *gandha* is instrumental in the achievement of the four ends of human life[7]:

"Through *gandha* one fulfills one's desires, *gandha* vouches religious merit, *gandha* brings wealth, in *gandha* is emancipation established" (Sastri 1972, p. 521).

Mānasollāsa of king Someśvara (1130 A.D.) while describing *dhūpabhoga* for the kings, mentions three varieties of *dhūpa* or incense: *cūrṇadhūpa*, powder, *piṇḍadhūpa*, roll, and *varttidhūpa*, sticks. The text, then, describes the clay-vessel for containing embers, with many holes on the upper side, for fumigating bed-rooms and the whole palace (Shrigondekar 1939, II, pp 144-45).

Patañjali in his *Mahābhāṣya*, II.1.1. refers to *campaka* and *mallikā* flowers. *Mahabharata*, III. 155 contains a description of *gandhamādana* forest which is

pervaded with inebriating fragrance of flowers of trees and plants such as *āmra*, *ketaka*, *bakula*, *punnāga*, *pātala*, *mandara*, *indīvara*, *pārijāta*, *devadāru*, *kumuda*, *kalhāra* and others. The *Bṛhatsaṃhitā*, LXXVII, 6, mentions a process for manufacturing synthetic *campakagandhitaila*.

Gode gives a brief history of ambergris and rose-water in India, both of which were introduced from Persia and Arabia. Regarding the former, he states that the Arabs or Mussalmans introduced ambergris into India sometime before 1000 A.D. This rich perfume became popular in India in a short time. About the latter he opines that the rose was introduced into India from Persia (Gode, 1961, pp.9, 25 ff). But Bhattacharji thinks that the rose is an indigenous flower-plant of India, since more than one species of rose grow in the Himalayas (Bhattacharji,1935,p.81 ff) Its ancient name *pātala* is mentioned in the *Mahābhārata* as stated earlier. As popularly known, *gulāb* is not the persian name of rose. In Persia, it was known as *gul*, i.e., flower, *par excellence*. The term *gul-āb*, in fact, means rose-water.

Āin-i-Ākbarī (1590 A.C) states that the Diwan-i-khās of emperor Akbar used to be fumigated with the preparations of ambergris and that the emperor weighed himself against gold, silver, musk and perfumed oil (Gladwin 1897, pp.65, 185 ff).

So far we have collected information regarding the use of scents and cosmetics from various literary sources, which tends to show that they were very popular and were extensively used in ancient India. The reference of *gandhataila*, scented oil, in the *Rāmāyana*, the use of the term *gandhayukti* in the works of the Buddhist era and the statement in the *Pañcatantra* regarding the trade in perfumery and cosmetics being the best of all, suggest that there must have existed a treatise on the specific technique of the manufacture of different items of perfumery and cosmetics, mentioned in the ancient literary works.

There is a distinct reference to *gandhaśāstra* of Lokeśvara and others and to a well-known terminology of that science in *Nāgarasarvasva* of Padmaśrī (Tripathi 1921, p. 11), a Buddhist writer on erotics[8] (1000 A.D.):

This hypothesis is corroborated by a newly found manuscript entitled *Gandhasāra* of Sri Gaṅgādhara (1500 A.D), with a Marathi commentary called *Gandhavāda* by an unknown commentator, in which the author calls himself a *kovida* in the *gandhaśāstra*, who composed the work after consulting many earlier authors on the subject who are significantly called *gandhagamajñaḥ*, experts in the traditional technique of perfumery. It also states that one should undertake the proper processes of *pācanadhūpana*, *bodhana* and others as known traditionally from those who are well-versed in the Veda and other *śāstras* through oral transmission.[9]

This work exclusively deals with the technology of cosmetics and perfumery from the practical point of view.

In the beginning the author pays his obeissance in three verses, to Vyomakeśa (Śiva), Gajāsya (Ganeśa) and *Gandhayakṣa*, who are conventionally held to be the presiding deities of the science of cosmetics and perfumery. The author then summarises the purposes of the *gandhaśāsana*, in the text two verses.[10]

"Here we shall deal with the science of perfumery, only by showing the direction, which helps the procedure of worship of gods, including the auspicious

scents and incenses, securing health and nourishment of men, tending to help achieve the three aims of human life, removing one's own poverty, vouching pleasure of kings and giving happiness to the minds of adept ladies".

The work is divided into three *prakaraṇas* or chapters entitled 1. *paribhāṣā* 2. *gandhodakādi* 3. *nighaṇṭuparikṣādi.*

The division of the subject-matter and its treatment is systematic and laconic.

For different substances, used for the manufacture of various items of cosmetics, the author suggests six processes[11]:

"The expert technologists have prescribed six processes for the substances, namely, *bhāvanam, pācanam,* or *pākaḥ, bodhaḥ, vedhaḥ, dhūpanam,* and *vāsanam.*"

Out of these six processes, *bhāvanam* is just saturating specific powder in scented water[12].

But the process of *pāka* or ripening is ninefold"- *Puṭapākaḥ, gartapākaḥ, venupākaḥ, dolāpākaḥ, kharparapākaḥ baijapūrapākaḥ* (which has two sub-divisions, namely *bilvapākaḥ* and *karabhapākaḥ*) *mūlapākah, hansapākaḥ* and *kalapākaḥ.*

The procedure of all these different modes of ripening is mentioned with details. For instance the *dolāpāka*[13] is described in lucid terms:

"The process of *dolāpāka* consists of ripening of the fragrant substance held in cloth and kept inside a clay-pot, the mouth of which is closed with an earthern plate and luted with clay, by vapour of scented water" (see *Fig. 1*).

After ripening, the third process is stated to be, *bodha,* revival of fragrance through reviving agents[14] like *kuch, punica-granatum, kola, peper nigrum* and *murā,* (*Selimum tennifolium*):

"Revival of fragrance has to be effected by reviving agents like *kuca, kola* and *murā.* Out of a quantity of ten units, revival can obtain one/fourth of the substance. The different types of scents acquired through this process are to be classified as *dala.*

The fourth process, called *vedhaḥ*[15] seems to be same as revival carried further:

" *Vedha* should be effected with the alcohol derived from *soma,* essences, recipes made from *cala, Michelia champaca, kira,* seeds of *Punica granatum* and *candraka* (*Eletteria cardamomum*). It may also be effected in some cases, with the substances used in *bodha,* having regard to their congeniality with one another"

Regarding the process of *dhūpana,*[16] fumigating, the text reads:

"First of all the substance should be fumigated with pungent smoke, then with intense smoke and thereafter with the smoke of *śara* (*Typha elephantina*). The wise, for the purpose of fumigating *Areca catechu* and other substances, should prepare appropriate *yantra* with proper arrangement of luting with cloth etc., if necessary". (see *Fig. 2*).

The final process called *vāsanam*[17] or aromatizing is very simple:

Though the second *prakaraṇa* is entitled *gandhodakādi,* perfumed water etc., it, in fact, deals with a great variety of items of cosmetics and perfumery, such as,

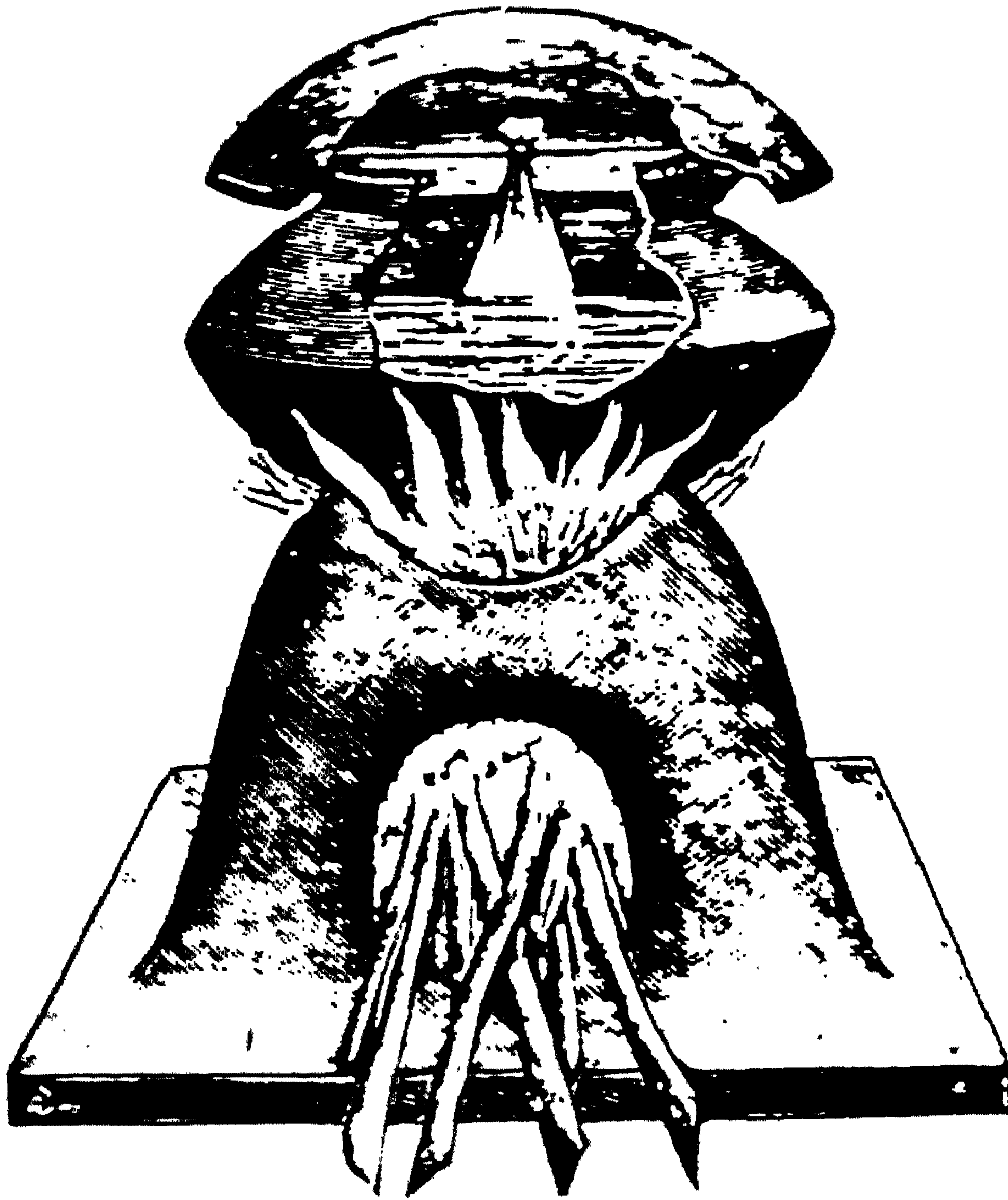


Fig. 1. Dola Yantra

pañcavidha-gandhajalam, udvartanam, snānajalam, jalavāsaḥ, mṛgarājaḥ, dhupaḥ, varttiḥ, uddhūlanam, niryāsaḥ, syandaḥ, kusumadrutiḥ, gandhasankramaṇam, kṛtrimadravyāṇi, dravyamelaka prakāraḥ, and others. This is also the most important and extensive chapter insofar as it has 392 verses as compared with 91 verses in the first and 120 verses in the third chapter, and also because it deals at great length with a good number of varieties of each of the items ennumerated above. For a clear understanding of the matter discussed in this chapter, the author has provided seven tabular presentations, out of the total ten, the remaining three being given in the third chapter. These tables are parts of the text, since the items mentioned in the columns and the number of combinations that could be prepared by their alternate use, are first described in the verses. For instance in verses 42-44 the author explains the manner in which a great number of combinations of incenses[18] can be made:

Thereafter, he presents a table of 16 × 16 columns as stated in these verses (*Fig. 3*).

The most interesting and significant items of incense are those which are to be used for hypnotising persons, removal of ghouls, getting rid of diseases like fever, protection of foetus and new-born child, keeping off bugs, mice, gnats, flies harmful insects and even poisonous reptiles and finally for captivating elephants. Only two instances will give an idea about such uncommon kinds of incenses[19] :



Fig. 2. Dhupana Yantra

"Incense made from *gada, saussurea lappa, nimbapatra,* leaves of *Azadirachta indica, medhyā (Litsea glutinosa), pura (Commiphora roxburghii), sarşapa (Brassica integripholia), yava (Hordeum vulgare), harītakī (Terminalia chebula)* and melted butter of brown cow, removes all sorts of fever".[20]

"By the power of incense made from the powders of *nimba (Azadirachta indica), sarja (Shorea robusta)* and *siddārtha (Brassica integripholia),* bugs, gnats, reptiles, mice and poisonous worms instantly vanish like weak deers and other wild animals by the appearance of a lion".

The Final *prakaraṇa* entitled *nighantu* provides a list of *dravyas,* substances, used in different items of cosmetics and perfumes and lays down norms of their *parikṣā* or examination before their actual use. Following the method of earlier *nighantus,* the author classified these substances into eight *vargas,* namely, *patra,* leaves, *puṣpa,* flowers, *phala, fruits, tvak, bark, kāṣṭha, wood, mūla, roots, niryāsa,* exudations, *jīva,* material derived from living animals.

कोष्ठ १	मुरा ६२	पद्मक १०	सारिवा ४४	मोथ ५	हिरडे ५०	चोर २३	पत्रक ४२
लोध्र १८	केसर ४७	कचूर ४	एकांगी ६३	वाल २२	खर्जुरको ४३	अगरु ६	लता ५१
उशीर ६१	वर्शोलतो १७	प्रियंगु ६४	तगर ३	एलावालुक ४४	मांसी २९	बले ५२	बोलु ७
सूद्मैला १५	कंकोल ६०	धणिया २९	सौंफ २६	श्रीवास ९	कुंदुरु ५६	गुग्गुलु	सालै ४०
गंधमुस्ता २२	जाइपत्री ३५	लवंग १६	चत्रत्वक् ५७	राल २८	नखी २७	नख १०	देवदारु ५२
लंवगत्वक् ५९	जाइफल १४	पुष्पकंकोल ३२	रोहिस ३०	दमन ५५	अशोकी १२॥	मरुवा ३९	वचा २६
बोल ३४	रेणुक ३०	तज ५८	सूद्मैला १३	सरसी ३८	लाद्दौ ३७	तमालपत्र ५४	सुरभी ११
तेजवती ६१	नली २	महामोथ ४५	चंपक २०	व्याघ्रनखी ४९	शेखर ८	सूल ४१	त्वक्पत्री २१

Fig. 3. Items of Cosmetics and Perfumery

It is evident from the discussion of the contents of *Gandhasāra*, a systematic treatise on the technology of cosmetics and perfumes, that there existed an unbroken tradition of technique for the manufacture of a variety of items of cosmetics in ancient India and that the people of this country have been indeed very fond of using them for both secular and religious purposes.

Notes

1. *mālāgandhavilepanadhāraṇamaṇḍana-vibhūṣaṇatthana*
2. *panyānāṃ gāndhikam paṇyam kimanyaiḥ kāñcanadibhiḥ*
   tatraikena ca yakrītam tacchatena pradīyate (Pa.I.13).
3. *gandhena gandhadravyena divyati vyāvaharati iti gāndhkaḥ*
4. *cūrṇikṛto va ghṛṣṭo vā dāhākarṣita eva vā, rasaḥ sammardajova'*
   pi prānyangodbhava eva vā, gandhaḥ pañcavidhaḥ proktaḥ
   (Kā. Pū. Ch. 68, vs. 37-38)
5. *yakṣadhūpo vṛkṣadhūpaḥ śrīpiṣṭo guru jharjharaḥ, patrivāhaḥ*
   piṇḍadhūpaḥ sugolaḥ kantha eva ca, anyonyayoganiryāsa dhūpa
   ete prakīrititaḥ. (Ra. Pū. Ch. 69, vs. 142-143)
6. *..........................śṛṇu tannetrarañjanam, yena*
   tuṣyati kāmākhya tripura vaisnavī tathā, sauviram yamunam
   tuttham mayurayamunam tathā,durvikā meghnilañca añjanani
   bhavanti sat, (Kā. Pū. Ch. 69, Vs. 55).
7. *gandhena lalhate kāmaḥ ganadho dharmapradaḥ sada, arthānāṃ*
   sādhako gandhaḥ gandhe mokṣaḥ pratiṣṭhitaḥ (Kā. Pū. Ch. 69, vs. 154-155)
8. *'lokeśvarādibhyo' pamatidurbhodhagandhaśāstrebhyaḥ,*
   sangṛhya sārabhāgam pravidhāsye suprasiddhapadaiḥ
9. *samyojayeducitapācanadhūpabodhān,*
   vedādyabhijñakathitāgamasampradayaiḥ (Ga. S. folio 21b)
10. *devānāṃ śubhagandhadhūpasahitasyārcavidherarpakaṃ, nṛṇām*
    puṣṭikaraṃ trivargafaladaṃ svasyāpyalakmīharam, rājñāṃ
    toṣakaraṃ vidagdhavavanitacittāprāmodapradam, śāstram
    sacchubhagandhaśāsanamato diṅmātramatrocyate (Ga. S folio 1a)
11. *bhāvanaṃ pācanam bodho vedho dhūpanavasane,*
    evaṃ ṣadatra karmāṇi dravyeṣūktāni kovidaih (Ga. S. folio 1a)
12. *piṣṭva gandhāmbuni dravyāṇyuktānyālodya bhāvayet (Ga. S. folio 1b)*
13. *vastraṃ gandhādravyagarbhaṃ bhāṇḍe sammudrite 'ntarā,*
    svedyaṃ gandhambubaṣpeṇa dolāpāka vidhistvayam (Ga. S. folio 1b)
14. *bhodhastu bodhakairdravyaih kucakolamurādibhiḥ,*
    daśāpiṇḍa caturthamśo bodhaḥ syatte dalāhvayaḥ (Ga. S.folio 1b)
15. *vedho hīndumādārkasaracalakīronu candrakaiḥ,*
    kāryaḥ kvacidbodhakaisca mitramitrāvivekataḥ (Ga. S. folio 1b)

16. *ādau kaṣāyadhūpaḥ syāttata ugrastataḥ śaraḥ, alepanādi vastrādi pūgādikavidhūpane, kartavyam tattaducitam yantraṃ saracaṇam budhaiḥ (Ga. S. folio 2a)*

17. *kusumairvāsayeddravyaṃ kalkamevam tu vāsayet, vilipya khar parasyāntaḥ kusumoparyadhomukhaṃ, kuryātkhar parakaṃ prokto vidhireṣo'dhivāsane (Ga. S. folio 2a)*

18. *atra caturṣu dravyeṣvekaikaṃ candrabhāgamitaraiśca, dvitricaturbhāgaiḥ saṃyuktaṃ dravyaiśca ṣadhedaṃ divitricatur bhāgaṃ cāpyevam śeṣāni cāpyevaṃ, militāḥ ṣannavatiḥ syurbhedaḥ ekasya yogasya sa ca ṣoḍuśakacchapuṭe nakhadhṛtisamkhyāḥ-(1820) yogaḥ syāt,tena ca rasenduguṇita nakhadriyugasailacan dra-tulyāḥ-(174720)syuḥ (Ga.S.folio 20a)*

19. *gudanimbapatramedhyāpuraḥ sarṣapayavaharītakībhiḥ, kapilāghṛtayuktābhiḥ sarvajvaranāśano dhūpaḥ (Ga.S.folio 14b)*

20. *nimbasarjarasasiddhārthācūrṇaprabhāvataḥ, matkumamaśakāh sarpāh mūṣaka viṣakitakāḥ, palāyante kṣaṇātsarve siṃhātkṣud ramṛgādayaḥ (Ga. S folio 15a)*

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Dyes, Mordants and Pigments

RADHA KRISHNAMURTHY

Man is a lover of beauty. He likes to add colour to the objects around or change their colours to make them look more beautiful and delightful to the eye. Colour is defined as a quality which can be cognised only by the eyes[1]. The moment any object is seen, the eyes are first attracted to its colour. Hence, ever since the dawn of civilization, man was inclined to make different objects more pleasing by painting them with beautiful colours and by dyeing a few objects like fabrics etc. in delightful colouring materials. Painting and dyeing have got their utilitarian value also. They protect the surface from getting affected in changing atmospheric conditions, hide the defects on the surface of different objects like structural walls, cloth, hair, etc., and prevent metals from getting corroded.

Colouring of any object can be done by means of dyestuffs and pigments. Though dyes and pigments are both colouring agents, dye-stuffs are defined as chemical compounds which have the property when in solution to colour vegetable or animal fibres permanently with or without the use of auxiliary agents (Riegal, p.508). Pigments are insoluble in the coating material whereas dyes dissolve in and colour the coating material. Pigment is an insoluble substance used to give colour or tint to paints and other surface coatings (Newman 1963).

Reason for dye activity among dyes is found in their basic or acidic substituents. It is easy to dye wool or silk because they are essentially protein and have both basic and acidic properties. But dyeing cotton is difficult without the prior use of mordants which are substances found to be capable of penetrating and adhering to the fibres. The dye added after using mordants forms an insoluble product in the cotton fibres.

It is indeed surprising that people in Ancient India and even those who belonged to pre-historic times had the knowledge of the properties of different colouring agents, both organic and inorganic, and knew the techniques of making use of dyes, mordants and pigments for colouring and painting different objects.

Dyes and Dyeing

There are many archaeological and literary sources to prove that the art of dyeing was in vogue ever since the dawn of civilization in India. Dyes and dyeing are problems with which man was concerned since ancient times. A dye is a coloured substance which imparts more or less permanent colour to other materials. All coloured substances cannot be used as dyes. Some coloured substances, usually organic chemical compounds may be added to cloth in water and after a period of soaking, usually accompanied by heat and agitation, the cloth will be coloured and the colour also remains fast.

Dyes which are prepared in the form of powder, paste or solution are utilized generally in colouring cotton, wool, silk, cloth of natural fibres, in cosmetics, in the manufacture of ink etc. Many soluble dyes are converted into pigments by forming insoluble salts (by replacing sodium in a dye salt with calcium) for use in lacquers, paints, etc(McGraw-Hill). Dyestuffs are used for artificial colouring of food articles and soft drinks. They are also used for colouring hair, fur, metals, etc.

Dyes for Textiles

In India, the art of using dyes to ornament fabrics has an ancient origin. The discovery of a fragment or maddar-dyed fabric at Mohenjo-daro sticking to a silver vase leads us to believe that Indus Valley people were acquainted with the technique of dyeing cotton with red colouring matter of the maddar root and that mordant process of dyeing cloth was known in India 5,000 years ago (Indian Printed Textiles, 1950). During this period spinning of cotton and wool seems to have been very popular among all classes of people for the whorls made of cheap as well as costly materials have been found. From the drawings of figures of men and women on the walls of these ancient sites, it becomes evident that Indus valley people donned themselves in clothes with different designs and that they were acquainted with the art of dyeing cotton with the red colouring matter of the maddar root after using some mordant. Since many dyeing vats are also found, it is proved that dyeing of fabrics was practised on large scales as a profession.

Vedic texts provided evidence to the fact that the art of dyeing and printing textiles had reached a developed stage even in those early days. It is said that the robe of a king who is initiated to perform Rājasūya Yajña was fully worked or painted with designs of various forms of the yajña. On the occasion of marriage, bridal dresses were beautifully decorated with lovely designs and golden motifs (*Śat. Br.* 5.3. 520). Mention of words like *rajayatrī* in Vedic texts clearly indicate that dyeing cloth was practised as a profession and a separate professional group was engaged in this (Śukla YV, Adhyāya 30; *Vāj. S.* 3).During this period, people were using cotton, woolen and silken cloths. Wool was first dyed in the desired colours and from this dyed wool, cloth was made (*Śat. Br.* 5.3. 521). The dyes used during the early period were natural colouring agents like saffron, henna, extracts of plants, leaves, flowers, fruits etc.

Buddhist literature also testifies to the fact that colours were obtained for dyeing purposes from the roots, stems, barks, leaves, fruits and flowers of trees. With these dye-stuffs many beautiful designs of flowers, hoods of serpents etc. were made on

the dresses of varied colours of the *gṛhasthas* (*MV*. 8.10.29). Among the dyes or colours used by ancient Indians, we find frequent mention of indigo (*nīla*),lac (*lākṣā*),turmeric (*haridrā*), maddar (*manjiṣṭhā*) and resin (*rajana*). In *Samyutta Nikāya* it is said that just as a dyer or painter with dyes or lac or turmeric or indigo or maddar and a well-smoothed wooden panel or wall or piece of cloth can produce the form of a woman or a man completed in every detail, similarly the uninstructed ordinary person brings body (*rūpa*) into existence, brings feeling, perception etc. also into existence (*SN*. III.22.100). The Vinaya texts of the Buddhists also describe six sources of dyes for robes - dyes made from roots, trunks, barks, leaves, flowers and fruits of trees. The dye was extracted from these raw materials and the robes were dyed in a trough. Ever sincce the day of Indus valley civilization, the process of preparing the solution of dyes in large vats and dipping and agitating the cloth in them were followed by the dyers.

There are many references to cotton fields, use of dyed cotton and silken clothes in ancient Prākṛt texts also. It is mentioned that cotton seeds were treated with red lac juice in a special manner to get red-tinged cotton(*Sar. S.* Arhaṭa Prakaraṇa) Dyed cloth was liked by everyone in ancient India, and women, especially, were proud of wearing dyed garments. *Raktadukūla* or red silk was very popular. Plantain green also was a favourite colour. Red blouse was considered an ornament for women. The orange-red colour is described as the colour of *kusumbha* flower. Literary texts of this period are replete with references to the colour indigo. Indigo is a very fast colour and was used in a large scale for dyeing cloth as it sticks well to the cloth. *Abhisārikās* who were eager to meet their lovers in the dark, used to don themselves in dark blue dresses dyed in indigo so that they could not be seen by others in the dark (*Gāt. S.* II.65; IV.60; VI.69; VI.45; *Gau V.* 255). Our ancients could name different colours and hundreds of different tints by identifying them with the natural colours of the flora and fauna.

Kauṭilya has furnished a list of different types of textiles, viz., *kṣauma* (rough silken cloth), *dukūla* (fine silk), *kṛmitāna* (Chinese silk) and *kaṅkata* (cotton cloth). In the list of dye- stuffs, *haritāla*, *manaḥśilā*, *hiṅgula*, *loha*, *varṇadhātu* etc. are mentioned. Among the different types of woolen dress material, Kauṭilya mentions *varṇaka* (dyed woolen blanket) and *saumitika*, a black woolen cloth spread on the howdah of elephants. Among the woven woolen cloth, there is a mention of *vanacitra*, a type of dress-material in which different floral designs are made in the weaving itself. This implies that yarns were dyed in various colours and woven in different patterns. *Bhiṅgisi* is another type of blanket in which eight pieces are joined to each other and this is black in colour. White shawls from Bengal and black ones from Puṇḍra Deśa are mentioned. Another cotton cloth well-known during the time of Kauṭilya was that fine variety from *Madurā* with different desings made of dots. It is quite probable that the famous tie-and-dye varieties of *Madura* saris are meant here (*AS* 1988. II.22.6; II. 11.103-108).

In the epics and purāṇas also we get many references which throw light on the popularity of dyed clothes among all classes of people. The garment of Añjanā was yellow with a red border. *Abhisārikās* attired themselves in blue clothes. The hermits' robes and also perhaps the dresses of servants were usually dyed in yellowish red colour (*kaṣāya*) (*Vāl R.* IV.66.12; VII.26.17; I.4.4 etc) As regards

dyes and colours, the purāṇas often refer to white, blue, yellow, red and multicoloured clothes.

It is well-known that Lord Kṛṣṇa is described as wearing yellow coloured clothes while his brother Balarāma is fond of blue robes. Even other deities are described as wearing different coloured clothes. In the list of occupations a *raṅgopajīvin* is referred to from which it can be inferred that the art of dyeing was well-known (*Bra. Pu* 44.30). It may also refer to a painter. Kṛṣṇa and Balarama defeated the *raṅgakāraka* of Kaṃsa and took away dyed clothes from him. Lord Kṛṣṇa is also described as wearing clothes decorated with powdered pigments of gold (*suvarṇāñjana cūrṇa*)[2]. From all these references it is evident that generally, locally prepared vegetable and mineral dyes were in use. Most common colours in the early centuries were white, red, yellow, green, black and blue. Some colours were of darker as well as of lighter shades. Some became deeply set after a wash, being coloured with the help of a machine. Even though the references to the technique of dyeing cloth with the help of machines are found in later medieval texts (*Bas. Pu.* III.V. 160), we may presume that this was practised even in ancient India because dyed clothes were very popular then.

Varāhamihira of about 6th century A.D. supplies lots of information on dyed clothes and garments of ancient India. We get references to garments of various colours, clothes dyed in yellow, blue, red, etc.and the people who wear them (*Bṛ.S.*LXXXVI.15.40; C.8; XXIV.18; LVII.32; LXXXVI.25 etc). White cloth was considered as best suited for dyeing in red, black and other colours.

Women attending auspicious functions like marriages and brides were attired in clothes coloured in *Kusumbha* flowers (*Carthalus tinctories*). Ascetics wore saffron red garments and were known as *kaṣāya* (*YY.* II.1; XII.14; *Viv. P.* 10.12).

Śivatattvaratnākara, an encyclopaedic work of the 17th century is a storehouse of information related to ancient Indian culture. We get information about different colours in which clothes were dyed. People were fond of wearing cotton, silken and woolen clothes collected from different parts of the country dyed in different colours like blue, black, smoky shade (grey), rosy pink, violet like *jambu* fruits etc[3]. Clothes were made beautiful with lots of attractive designs of animals and birds and also with different patterns of lines and dots in red, black, yellow and green colours. Clothes were dyed in *mañjiṣṭhā, lākṣā, sindura, haridrā, nīlī, abhaya*, (extract of a yellow myrobalan tree),etc[4]. Kings were advised to wear parrot green and peacock blue coloured silken and cotton clothes in spring season, white in summer, red woolen clothes dyed in *mañjiṣṭhā* in rainy season. Beautiful pink and grey clothes of very fine quality should be worn in autumn. In winter and during travel, clothes dyed in *kusumbha* and *lākṣā* should be selected. From these references and also those in other texts like *Abhilasitārtha Cintāmaṇi* of Someśvara of the 12th century, we can gather that all types of clothes like woolen, silken, fur and even those made from plant fibres were dyed in different pleasing colours.

Several other literary works in Sanskrit of the early centuries also contain many references to the wide use of dyed clothes in ancient India and that particular colours like blue, red, etc. were liked by all classes of people.

The above instances are adequate to provide ample proof of the developed state of textile industry in ancient India and particularly that of textile dyeing industry in those days. Even though direct information with regard to the technique applied in dyeing industry is very meagre in the ancient texts, to some extent it can be inferred from the references to the materials mentioned therein.

Mordants

Dyes which have little or no affinity for certain substances may yet be fixed on them if a mordant is first applied. Mordants are substances found to be capable of penetrating and adhering to fibres. Since wool and silk have both acidic basic properties, they are easily dyed. But dyeing cotton is difficult as it requires the prior use of mordants. The dye added after mordanting forms an insoluble product in the cotton fibres.

The discovery of a fragment of a maddar-dyed fabric at Mohenjo-daro is a strong evidence to prove that the mordant process of dyeing cotton cloth was known in India 5,000 years ago. The hundreds of references in our ancient texts about dyed cotton fabrics in different colours with different floral and geometrical designs suggest that dyers of ancient India knew the use of mordants and selection thereof for different types of textiles.

Early in the 6th century A.D., Varāhamihira has alluded in *Bṛhat Saṃhitā* to the preparation of fast dyes for textile fabrics by the treatment of natural dyes like *mañjiṣṭhā* with alum and other chemicals (like sulphate of iron, *kāsīsa* in *Sanskrit*) as also with cowdung[5]. *Tuvarī (alum)* is described as colour-binding substance of maddar. It is well-known that alum and sulphate of iron are even now largely used as mordants.

Tuvarī or alum is described as a fragrant earth produced in the mountains of Surat in Saurastra and which dyes cloth and fixes the colour of maddar. It is called *saurāṣṭrī* also and when applied to white cloth it serves as a mordant for dyes. A variety of it is slightly yellow and is called *pītikā* and another variety *sphuṭikā* is soft and acidic[6]. The two varieties of *tuvari* are also called *phullikā* and *khaṭikā*[7]. In *Amarakośa* of 600 A.D., *kāṅkṣī*, *tuvarī* and *saurāṣṭrajā* are mentioned as synonyms. Since a large number of dye-stuffs and dyed textiles are mentioned in ancient texts, it becomes evident that dyers were using basic mordants like iron sulphate and aluminium sulphates for acid dyes and that for basic dyes, acid mordants like tannic acid were used.

Since all dyes are not soluble in water, they have to be rendered water soluble by reduction or they have to be synthesised on the fibres (usually cotton) by means of methods like diazotization. Indigo or *nīlī* which have been very popular ever since the pre-Christian era and was an article of export to Egypt and other countries, is also an insoluble dye (vat dye) and our ancients knew the technique of making it soluble by reduction with which the dye could be impregnated in the cotton fibres by exposing to air or by oxidization. Besides alum, iron sulphate, etc., rind of lemon, flower of cotton, lime, lemon, green dried mangoes, myrobalans etc. were also used as fixing agents or mordants. Mordanting effect of each varied and each one

influenced that final colour obtained. In some dyes, alum produced yellow colour, in other it yielded orange blue (Jaggi, I.p. 165)

Dyes and Cosmetics

Dyes were used in cosmetics also. Chief among the cosmetics in ancient India was a paste of sandalwood, often coloured with lac and other dyes, smeared over the body and applied in different patterns. Collyrium (eye-salve) or *añjana* made of dark powdered antimony was very popular. Vermilion (*sindura*), lac (*lakṣā*) and a yellow pigment *gorocana* were used for marking as *tilaka* on the forehead. Lips, tips of fingers, toes, the palms and soles of feet were often dyed with red lac. Exposed parts of the body were also often painted with these dyes in different designs (Basham, pp 212-213). Betel leaves were chewed with lime and areca to redden the lips.

Works like *Nāṭyaśāstra* supply funds of information regarding the use of dyes in beautifying the body[8]. Even children used to paint their body with colouring stuffs like extracts of minerals (*dhāturasa*). *Mehndi* or henna, a colouring material was used for colouring the palms, soles of feet, nails, hands, etc.

Henna, well-known by the names *mendi, mendhikā, mehndī, marudāṇi*(Tamil), *gorante* (Kannada), all over India is a perennial shrub grown in India and Indian women are fond of making a paste of these leaves with lime for colouring their palms. It leaves a brownish red colour. A reddish dye is extracted from the leaves. The popular *mendī* or *mehndī* is identified with *madayantikā* which was used as an unguent or *aṅgarāga*[9]. *Madayantika* in Suśruta Samhitā (*Ci*, Ch. 25) is described as a dye-stuff to colour the nails (Gode, p 351). In the tantric work *Rasārṇava*, *madayantikā* is said to belong to *pītavarga*, a group of yellow dyes[10]. Even though it is said that *henna* leaves were used in ancient Egypt and Rome for colouring the hair, Indians also were equally acquainted with this colouring material known by the name *Mendī* eversince the ancient days, especially in South India.

In *Rasaratnakara*, a few recipes are given for the preparation of *kunkuma* (used as *tilaka*). Boiled essence of *palāśapuṣpa* should be kept in the sun in a wide vessel. In that should be dropped rice powder in the proportion of 1:20. Then lime, of half of the volume, should be mixed and stirred well in bright sunshine. Out of this, pellets can be prepared which will have bright red colour like *kuṅkuma*. Rice and *palāśapuṣpa* should be ground well into a soft paste and then dried to make pellets of *kuṅkuma*. *Kuṅkuma* can be prepared from *gairika* and *rajanī* with soaked wood of neem or coconut shell (*RNa, Gandhavāda* Sec. 115-119, Gode, p. 91). In a similar manner coloured *raṅgoli* were also prepared.

Hair dyes

People in ancient India were highly fashion conscious and they used special dyes to blacken their grey hair. Varāhamihira gives a method of preparing hair dyes from *kodrava taṇḍula* (grains of *harika, Paspalum scrobiculatum*) and *Loha cūrṇa*.(*Bṛh. S*.77.1-3) In the Bower manuscript, there is a mention of sulphates of copper and iron boiled with the oil of beleric myrobalan as a remedy for turning grey hair into black in a formula for hair-dye (Bower Ms.,Ray, p.68). Even though the manuscript

is said to be of the 14th century A.D., the contents should represent knowledge acquired in earlier centuries. P.K. Gode had made mention of a very ancient work *Nāvanītaka* of 2nd century A.D. in which recipes for hair dyes are given. It is advised that after washing the hair with chebulic and emblic myrobalans, the hair should be anointed with a paste of *alambusa* (*Sphaerantus indicus*) and indigo. A paste of indigo, rock salt, long pepper with water is a hair-dye which will turn the grey hair black as antimony. Several such recipes are given to prepare hair dyes (*Nāvanītaka*, Gode, Vol.I)

Among the several ingredients prescribed for the preparation of hair-dyes, several plants and minerals are included as colouring agents. *Rocana* (Bezoar), *Kācamācī* (Solanum nigrum), *nīlikā*, *nīlī* (dyers indigo), *abhaya* (*harītakī*), inknut, *ayoraja*, powder gum, *tuttham* (copper sulphate), *kāsīsam* (iron sulphate, green vitriol), *nīlotpala* (blue lily), *jambū* (black plum), *kakubhaphalam* (fruit of *Arjuna* tree), *añjanavarṇa* (mud of the colour of *añjana*), *asana kaṣāya* (extract or dicoction of asaṇa), *mardayati* (henna) and a few more.

Madayantikā, which is mentioned in many ancient texts, is mentioned in *Navanītaka* as an ingredient for hair-dye. It is identified as *mendī* also for colouring nails. Hence *madayantikā* was, no doubt, a plant yielding a dye used in the preparation of cosmetics and hair-dyes during the 2nd and 3rd centuries A.D. Some of the ingredients given above were obviously used as dye- producing agents in hair-dyes. Some among them were used as dye- producing agents in ink manufacture also.

Dyeing agents in ink

Dyeing agents are required in the preparation of inks also. The relic vase of the stupa at Andher, believed to be of 2nd century B.C. contains inscriptions written with ink on its surface. The inkpot found during the excavations at Taxila was on examination found to contain black carbon mixed with earth and this provides an evidence for the use of carbon ink in ancient India during the Kuṣāna period. (Archaeological Report, 1929, 30.209). There are several other archaeological evidences which throw light on the use of ink even before the Christian era. In ancient times, red lead and minium (*hiṅgula*) were used as substitutes for ink. The Kharoṣṭi documents from Khatan prove the use of ink in the 1st century A.D. Ancient painted inscriptions are still found fresh in the caves of Ajanta. The Jains have also used coloured inks extensively in their manuscripts. Professional writers were known by the names *lipikāra* and *śāsana lekhaka* (*Śiv.R.* V 15.86). It is well known that scholars and poets were writing on birch bark and palm leaves.

All these references imply that ink was used extensively for writing and that ink manufacture was in vogue. Ink for writing on *bhūrjapatra* (birch bark) was made by converting almonds in to charcoal and boiling the coal thus obtained with *gomutra* (urine bovis). Though nothing much is said about the recipe of ink in any ancient texts,in lexicons like *Śabdakalpadruma* we come across many synonyms for *masi* like *masijalam*, *kālī*, *añjanam*, *rañjani*, *maliñambu*, etc. We can gather a few details regarding the preparation of ink in ancient India from a few sources of the later medieval period also. Buchanan has recorded ink manufacture in the form of liquid and solid. Lampblack was collected from earthen lamps of linseed oil and

was mixed with the gum of Mimosa indica and a little water and rubbed in an iron mortar for three hours. Gall nuts were infused in the water and strained infusion was added to the rubbed material. After rubbing for six hours, the pot was kept in sunshine till they reached the consistency to make small lumps which were again dried in the sun (Ray, pp. 235- 36; Gode, pp.24-25). Even today lampblack is used as an essential ingredient for ink with an addition of gum, inknuts, sugar, etc.

Jain texts contain preparation of different inks for writing on paper and on palm leaves. The former is made by mixing a coffee coloured infusion of roasted rice with lampblack and then adding sugar and sometimes juice of a plant called *kesurte*. For the other type also juice of *kesurte* was used with a dicoction of wheat flour. Since such inks are completely free from mineral substance, strong acids do not injure the substance of the paper and hence the writing never fades and it retains the gloss also.

Generally the dye-stuffs producing black and red colour were used in preparation of inks. Sometimes *haritāla* (yellow orpiment) also was used. The use of haritala was very common in old manuscripts for correction of letters or deletion. Clothes were marked with marking inks known as dhoby's ink prepared generally from organic dyes like ink nuts etc. free from carbon.

Rasaratnākara of Nityanāthasiddha of about 1200 A.D. gives recipes for preparing ink for writing on palm leaves and birch barks. The ingredients prescribed are *abhaya* (*harītakī*, chebulic myrobalan), *āmalaka* (Emblic myrobalan), *nīlikā* (dyer's indigo), *kāsīsam* (Green vitriol), *vibhītaka* (Beleric myrobalan), *kārṣṇayam* (black iron), *sahacarapatram* (*Justicia ecbolium*), oil of *vibhitaka*, flowers of *sahacara*, seeds of mango, *asanakusuma* (flowers of kino tree), *lohacūrṇam* (powder of iron), extract of decoction of *asana*, etc. Most of the above ingredients are no doubt dye-producing agents used in the preparation of inks of various colours (Ray, p.236)

Several literary works of ancient India contain many references to the use of cloth for writing, particularly for writing letters. *Valkalapaṭṭikā* or piece of bark garment was used for writing purposes. Passages from *kādambarī* of Bana refer to this and also to the use of fine white cotton stuff. The main ingredients that are mentioned in these passages are the extracts of leaves of *tamāla* tree mixed with the fragrant ichor of elephant and a dark blue dye.[11]

Other uses

Ancient Indians knew the technique of adding *kunkuma* (saffron) dye to *karpūra* or camphor powder by placing the camphor powder in a crucible after treating it with *kuṅkuma* (*Śiv.R.* VI. 25.50,51) In those days, drinks and sweets were also covered by adding approved colouring agents. We get a suggestion of this in *Śivatattvaratnākara* which gives a method of colouring curds (*Śiv. R.* VI. 19.234-127).

From the various references mentioned above from ancient and medieval texts, it becomes clear that along with the art of spinning and weaving, the secondary art of dyeing also flourished in Ancient India. Most of the colouring substances were obtained from vegetable sources like roots, trunks, barks, leaves, flowers and fruits.

The dyers' class known by the name *rangakāraka* made their own colours and solutions from the raw materials. Generally, dye-producing vegetable substances were diluted in water in the form of powder, juice or lump and then boiled for preparation of dyes. Dyestuffs from animal sources were obtained by soaking the insects in water and squeezing them. Mineral colours were obtained by means of simple chemical processes.

Metals and Minerals

At the beginning, even though natural organic and plant materials were used as dyes, in the course of the Gupta Age, as Tantric cult developed and alchemical techniques were practised, dyes also were prepared from minerals and other substances by means of several chemical processes. The art of dyeing, in this manner, has indirectly helped the development of chemistry in ancient India.

Mineral dyes were utilized in colouring cotton, wool, linen, silk, cloth of natural fibres, ink, hair, cosmetics etc. Many soluble dyes were converted into pigments by forming insoluble salts for use in paints, inks etc. Many works of the Tantric period contain information on dyes being utilized in colouring metals also.

In the texts dealing with alchemy and allied topics of ancient and middle ages we come across words like *loharañjaka rasarañjaka, sūtarañjaka* etc[12]. It is quite probable that in 4th or 5th century A.D., people were efficient in the techniques of colouring metals and minerals for several purposes. *Rasārṇava*, a tantric work says, "Iron, lead and copper are coloured by means of calamine - the whole thing turns into gold".[13] *Rasaka* (calamine) is of three kinds, of the colour of the earth, of the colour of stones and of the appearance of treacle. *Rasaka* mixed with certain organic matters and roasted three times with copper converts the copper into a golden stuff. To obtain vermilion (*sindura*) of the colour of rising sun, it is advised that ash of mercury and sulphur of equal weights should be rubbed and roasted in a covered crucible. Blue vitriol (*tuttham*) which is of the colour of the neck of peacock, saffron (*kunkumam*), calamine (*rasaka*) and also the excreta of a young calf, the poisons (*visa halahala*), powdered *Plumbago zeylanica*, (*raktacitracūrṇa*), all in equal proportions should be rubbed with acids and dried in shade.

Then adding honey to the mixture it should be smeared on a thin sheet of lead. When roasted in a covered crucible, the lead gets a beautiful colour fit to be used for bedecking gods (*Rṇv* VII.31-34; XIV.81; XVII. 70.74; Ray, pp 138-139).

Apart from the Sanskrit texts dealing with alchemy in ancient India, a few Tibetan texts also furnish some information on the chemical process of colouring metals with organic and inorganic dye-stuffs. *Bilva* (wood apple), *dāḍima* (pomegranate) and a special kind of dye (*smantshos*) are to be burnt and mixed with sour wine in a copper pot for three days. In this manner, a paint will be prepared which should be applied twenty one times to a thin piece of iron and it becomes copper (copper coloured) [*Dhātuvāda*, 2,3, vide Ray] for Extracts.

A plant named *kuṣṭha* (*Costus speciosa*) grown in the Himalayas are often mentioned in ancient Indian medical texts. It is said that the leaves of this plant drop a fluid towards the earth having a colour like bright gold. This has a dyeing effect when comes into contact with the ashes of pure lead and quicksilver. It turns copper

mixed with silver into a golden material (*Dhātuvāda* 12). *Hiṅgula* alum, blue vitriol etc. are said to be favourable for importing colour to quick-silver (*Śiv. R.* VI. 15.50-51; *RHr*, Pātala VIII). To brighten the blue tinge of the precious stone *nila* (sapphire), it is said that the gem should be placed in a bronze vessel filled with indigo juice mixed with the juice of citrus fruit (*Śiv. R.* VI. 17.112)

Pigments

Pigments are insoluble substances used to give colour or tint to paint and other surface coatings.It is generally distinguished from dye which is soluble and penetrates the tissues of fibres of any organic material (Newman, Vol.I). Pigments contribute to the optical and other properties of paints, finishes and coatings. Pigments for paint should be insoluble in their vehicle and chemically inert to it. They should have good covering or spreading power and clean intense colours. Since they are insoluble in the coating material, they are mechanically mixed with the coating and are deposited when the coating dries up. Their physical properties are not changed by incorporation in and deposition from the vehicle. Pigments may be classified according to composition as organic or inorganic or by source as natural or synthetic.Generally,for all practical purposes the classification may be done by colour or by function (McGraw-Hill, Vol-4). Since the pre-historic days, pigments were used in preparing slips and paints for potteries, for artistic paintings of pictures and portraits, for coating surfaces and walls etc.

Pottery Painting

Pottery and pottery-painting were practised in India ever since the dawn of civilisation.People in very ancient settlements were well-acquainted with the art of making potteries of burnt clay and painting various designs on them. A large variety of ochres, haematites, pigments and organic colours were used by potters for slipping and painting the pots.

Archaeologists are of the opinion that various earliest settlements of pre-historic India that have been unearthed represent independent cultures of their own and a classification has been made on the basis of techniques employed in pottery painting. From this is implied that these inhabitants of very early settlements were well-acquainted with the techniques related to pottery making and painting which involved the use of varied pigments for slipping and painting the clay pots.

The art of painted and polychrome pottery had also developed. Actually, this knowledge of the prehistoric man in making use of different dyes and pigments to beautify objects like potteries and also the simple techniques he adopted for that purpose led to the development of paint technology in India.

Regarding the pre-historic cultures, archaeologists have given a broad classification as Buff-ware culture and Red-ware culture based on the colours of the potteries found in those settlements. The potteries of the former culture have a buff-body painted over with designs in a purplish brown or black paint. The Amrinal pottery body, generally, is a very fine buff or pink and white slip is frequently applied as a background for painting designs. Polychromic pottery vessels with red, blue, green and yellow paint were also found in this settlement.

Another series of sites of settlements of pre-historic India representing the Kulli culture is characterized by its painted pottery styles. Clay figurines also have been found here. The painting of the pottery body here is generally of black colour with an occasional use of red or white colour on which designs are also painted.

The Zhob red-ware culture show more or less a distinctive painted pottery style with a red pottery body. The painting is stylish with red and black designs on the red body of the pots (Ray, pp.1-2).

During Indus valley civilization potteries were produced on a mass scale on potters' wheel. Though the pottery is for the most part plain, decorated and painted potteries were also made by the Harappan workers. Black geometrical designs were painted on a deep lustrous slip.

This characteristic of 'red and black' pottery of Harappan civilization is easily recognizable. A few polychrome potteries that have also been unearthed in these sites are painted in green and red on a buff slip. Chemical analysis has revealed that red or solomon colours in these objects are due to the presence of iron components in the clay. The slip of bright red colour found on some potteries is due to ferric oxide. The black and chocolate designs that are found painted on the body owe their colour to oxides of manganese. The colouring agents used by the Indus valley people are used even today by potters. Many of the ancient techniques of selecting and applying colouring materials have come down to the present time also.

A large variety of ochres, haematites, pigments and organic colours were used by the potters of ancient India as they are done today. As a rule, slip treatment also was given to the pots before they were fired. Slipping serves two purposes it helps in closing the pores and secondly, it provides smooth surfaces helpful in painting a design on them. Slipping was done by dipping the pot after burnishing in a solution or by painting with a solution formed by the finest portion of the clay used for making the pot or of any suitable material. For slip preparation also ochres, pigments or clay were considered as suitable materials.

The colours of slips used at Mohenjo-daro were buff, cream, pink and red. The first two seem to be natural ones. Lighter pink shades are attributed generally to traces of iron in the clay which on firing threw a pink colour. But the darker pink shades seem to have been produced by the addition of a slight red colouring. Red slips were produced by mixing red ochres with the clay or by using red ochre itself in solution as a slip. Dark red colour of the slips seems to have been derived by the use of red oxide in the slip (Jaggi,I,p. 100). The colours of these slips neither vanish nor fade in firing.

As of today, in ancient India potters were preparing slips with red or yellow ochres which when applied emit a lustre on the surface. For black and chocolate shades, a manganiferous haematite. was used. Different varieties of ochres and haematites, which are known today by different local names in different parts of India, were made use of for colouring slips, like *geru raṅgamati, dhau, multānimaṭṭi*, etc. It is said that the manganese oxides frequently associated with ferric oxide give a pure black colour when rich in manganese. If iron in the mixture preponderates it gives a chocolate colour.

Excavations at Sanci, Taxila and other places also have revealed further information regarding the character of pottery in India from about 500 B.C. to 100 B.C. The body of the potteries of these different sites consist of a finely levigated clay, usually grey but sometimes reddish in sections. This is covered with a brilliantly burnished slip having the quality of a glaze, with colours from jet black to grey, metallic steel blue occasionally varied with reddish brown patches.

In this context, it is noteworthy that the polished stone surfaces of many of the Sanci stupas were reddened with a translucent stain which has the advantage of not obscuring the texture of the stone or the delicate details of the carvings. Sanci paintings on walls have been found to be made by mixing red ochre with lime-wash to give red or *geruka* (brownish yellow) colour (Ray, pp. 77-78). Red lead or minium has also been found as an ingredient for the application of red paint. Excavations at Arikamedu in the 1st and 2nd century A.D. have brought out potteries with burnished slips and some of them are glazed. The polished bright red slip has been identified as haematite. A slip of ferruginous clay was also applied to some (Ray, p. 83)

The potteries unearthed from the pre-historic sites like Mohenjo-daro and Harappa and later on at Sanci and other places reveal the fact that people of these ancient days were acquainted with the properties of different colouring materials and pigments. Different varieties of ochres and haematities were used to prepare slips of different shades. The methods of slip preparation also varied from place to place. Most of the potteries found in these settlements were also painted. The technique of painting pots before firing and also painting designs on them after firing was in vogue. Mostly organic colours were used to paint the surfaces. For white pigment, lime, limestone, chalk and rice powder were used. To prepare black pigment, burnt cocoanut shell powder, soot, powdered charcoal, black iron oxide etc. were used.

During Vedic times and later on, ritual pots were painted with floral and geometrical designs in red, yellow blue and green colours. Vermilion (mercuric sulphide) or *dhau* (ruddle) was used from red pigment, yellow colour was obtained from turmeric or from yellow earth (a kind of ochre), blue from indigo, green from leaves, of particular trees and iron sulphate. Grey was prepared from a kind of haematite, orange pigments were obtained by mixing red and yellow colours. Copper sulphate was mixed with red pigment to obtain purple pigment. Usually these pigments were prepared in plain water.

Since different types of ochres, haematites, and local mud etc. were used for slips and also for painting the potteries, it is evident that methods like filtration, decantation, rubbing on a slab of granite with water, boiling with some other ingredients like calcium, *khadira* (catechu), soda etc., collecting barks and leaves from particular trees and allowing them to sour by adding rice starch etc. were adopted in preparing the pigments.

Archaeologists have unearthed another important variety of pottery from the ancient Harappan sites known as faience. It is a vitreous substance with a glazy surface often coloured by the addition of suitable mineral matters (Ray, p.12).

The painted grey-ware pottery is also well known from 100-400 B.C. approx. It is a thin grey deluxe ware, wheel made, well- burnt, glossy and painted with many decorative motifs.

Tinted Glass

Even though no glass objects have been recovered from Indus valley areas, in ancient Indian literature there are references to glass and coloured glass articles which give evidence to the manufacture of glass and its use in India as early as 800 B.C. (*MV*.VIII.3; *Cu.V.* IX.1; *Rām.* II 90.27; *ÁS* II.11). Archaeological evidences also prove that glass beads, bangles, jars, tiles etc. were made from 6th or 5th century B.C. onwards. Most of the glass objects were coloured.

Glass manufacture which was practised as an indigenous industry in ancient India and particularly in the south is brought to light from excavations at Arikamedu, Uraiyur and other places. Along with this, the technique of colouring glass also developed.

The glass specimens show that the glass makers of ancient India were highly competent in giving different colours and shades to glass objects. Chemical analysis has revealed that the colouring agents were obtained generally from the metallic ores. Different chemicals added to them finally led to attribute different shades of colours and glazes to the glass objects. Coloured glass was prepared by mixing silicates of soda, lime and appropriate metallic oxides (Jaggi, I p.203). Copper oxide, iron oxide, manganese oxides were generally used to give colours to the glass articles. Different coloured glass beads of the early centuries with yellow matrix covered with green glass were discovered in Nasik, Kolhapur, and some other parts in South India and these are said to be of Satavahana period. A special type of glass beads of 350 A.D. to 750 A.D. found at Ahicchatra is of gold foil glass. Layers of gold foils were poured in between two glass layers. All these prove that craftsmen in ancient India were highly skilful in the sophisticated technique of using metallic ores and chemicals as pigments in colouring very high temperature melting media like glass.

Art Painting

According to mythological sources it is believed that the principle of art painting was produced in the days of yore by the great sage Nārāyana for the benefit of the world when he created the celestial nymph Urvaśī. The great sage used mango juice to create the beautiful nymph by drawing with it her picture on his thigh. From this painting Urvaśī emerged as a lovely maiden. Thus the first picture of painting was created with mango juice as the colouring material. Through this beautiful picture the sage Nārāyaṇa imparted the principles of perfect portrayal through different colours to Viśvakarma (*Vi. Pu*, Citrasūtra, 35, 1-5).

However, leaving aside the mythological episode, the origin of paints dates back to pre-historic times when the people of that early period recorded some of their activities in colours (generally red and black) on the walls of caves. These were only crude earths or clays suspended in water. By about the Vedic period, ancient Indians had a wide number and variety of colours for painting pictures.

In pre-historic cave painting, *gairika* was used as a pigment and black colour was painted with burnt wood. During Indus valley civilization, white, red, black, yellow, green colours were used. Painting had developed well in Vedic period also even though no specimen is available. Buddhist literature also is replete with references to different types of painting in different colours (*Kus* , 531; *MV* .5.10. 3; 8.29). Auditoriums were decorated with beautiful paintings on the wall (*Nāṭ*. 290-291).

In the Ajantā caves, the paintings in the 9th and 10th caves are said to be created in 1st or 2nd century B.C. Specimens of paintings of Gupta period can be seen in the other caves of Ajantā, Badāmi Bāg, Chittannavāsal in Tamil Nad, and also in the temples of Kanci and Tanjore at South India. In Ajantā paintings extracts of plants and minerals were made use of in preparing pigments. First, the wall of the caves were prepared with a special *lepa* or coating and then the outline of the figure to be painted was drawn with black lines. Ellora mural paintings and Tanjore paintings of the 11th century are very famous for the beautiful depiction of figures in attractive bright colours and tints.

At Ajantā, Bāg and other caves, the colours most freely used were white, red and brown in various tints, a dull green and also blue. For white colour, sulphate of lime was used. Red and brown tints were obtained from compound of iron. Blue colour was obtained by grinding calcined lapislazuli - a costly semiprecious mineral usually imported. For yellow, the ancient painters used orpiment, a natural arsenic sulphide. In fresco paintings the pigments should be capable of resisting the decomposing action of lime and hence extra attention had to be bestowed upon selection of proper pigments. The fresco paintings testify to the knowledge and skill of the painters in preparing permanent colours out of vegetable and mineral sources.

In ancient and medieval period, as seen even today, the main doors and entrances of houses were decorated with the figures of Ṣaṣṭī Devatā, Nāga, auspicious motifs like *svastika*, lotus etc. These were done with a paste of *haridrā*. Doorsteps of Hindu homes were decorated with colourful designs drawn with coloured powders called *Raṅgoli*. Red ochre, chalk powder, charcoal. green powder of dried leaves of some plants, *haridrā*, *nīlī* etc. were used for drawing *Raṅgoli*.

Varāhamihira has referred to the art of painting as *citrakarma* and painters were known as *citrakāra*, *citrajña*, *alekhajña*, etc (*Bṛh. S.* LVII.14; V.74; IX.30; X.10; XVI.12)

It is declared that among all arts and skills, painting is the foremost. Just as Sumeru is the best among mountains so also painting is the foremost among all arts (*Vi Pu.* II.43.39). This suggests that ancient Indians knew the art of selecting colours and mixing them to achieve different shades. Vātsyāyana has summarised the principles of the art of painting of the 8th century A.D. under six categories amongst which *varṇikabhaṅga* or mixing of colours is one [14].

From these references it becomes clear that the art of painting was in a highly developed state even in ancient India and that people knew the technique of preparing pigments for painting beautiful pictures and also suitable vehicles or media for the pigments.

Among the Purāṇas, *Viṣnudharmottarapurāṇa* is valued as an authoritative work on the techniques of different aspects of the art of painting. To begin with, it gives a recipe for preparing a *lepa* or coating to smoothen the wall before painting a picture on it. It is said that three varieties of brickpowders should be mixed with a third proportion of it with clay. To this should be added fragrant gum-resin (*guggula*), bees wax (*madhucchiṣṭam*), honey (*madhu*), a type of grass (*kuṇḍaraka*), molasses (*guḍam*) and safflower (*kusumbha*) soaked in oil, in equal proportions. Powder of lime three-fourths burnt with bel fruit pulp and lampblack should be added. After adding one-fourth part of sand, the mixture should be soaked in water for a month to make it lubricous. With this paste a smooth and firm coat is applied on the wall (*Vi Pu.* III.40.1-10).

White, yellow, red, black and blue, these are the five primary colours and these in different combinations in different proportions produce hundreds of intermediate tones[15]. This work gives formulae for different colour compositions also. Blue and yellow when mixed produce green colour. It may be pale with a greater medium of white or deeper with blue. There are three distinct shades of each colour by mixing white in less, equal or greater proportions. Green colour can be obtained by mixing yellow and blue. It may be retained as pure green or it may be made pale green by adding white. The green colour may be made deeper by aggravating blue. Thus, by enhancing or lessening of the colours mixed, many subtle varieties of any colour could be created. Beautiful tints are produced by mixing in calculated proportions different colours. As an example it is said that red *lākṣā* tint mixed with white like the *lodhra* flower becomes red like the lotus, a colour extremely charming. Some of the tints produced with one predominant tone are given like yellowish green of *durva* grass, light wood apple green, green like green pulse, blue like blue lily, and so on.

The colours mentioned in *Viṣṇudharmottarapurāṇa* are of mineral and vegetable dyes like yellow orpiment (*haritāla*), lime (*sudhā*),lac (*lākṣā*),vermilion (*hiṅgula*),indigo (*nīlī*),lapislazuli (*rājāvarta*), red lead (*sindura*), lead (*trapu*), lampblack, mica, etc. and several more[16].

Colours can also be produced from metals in the form of very thin and fine sheets or a liquid. These metals are gold (*kanaka*), silver (*rajata*) and copper (*tāmra*). Metal colours are to be laid in delicately thin sheets or by liquefying them by chemical methods. Hide glue and *bakula* resin glue act to fix and strengthen the colour for which vermilion juice is also added. Juice of durva grass, bark resin, glue of elephant hides etc. fix and strengthen the colour of the pigments and these cannot be destroyed even when washed.

Poets like Bāṇa and others have mentioned subtle shades of colours in their literary works. The colours mentioned are not just poetic fancy because works like *Viṣṇudharmottara-purāṇa* have suggested a myriad by clever combinations of colours in various proportions. Literary works in Sanskrit are replete with references to shades and tints produced by different combinations of colours. Yellow and blue make green while red and blue make purple. Peculiar white of *haritāla śaila* is different from swan white. Red is found in different tints like that of *bandhuka* flowers, *kuṅkuma* red, *kusumbha rāga* red, blood red like a bunch of *ghātakī* flowers, *sindūra* colour of *mandāra* flowers, *manjiṣṭha* red, reddish like

the morning sun and so on[17]. Likewise, different shades of other colours including black and white are mentioned or suggested in different contexts. All these imply that people in ancient India were highly colour conscious and were able to prepare different paints by combining two or three colour pigments.

Śilparatna, *Abhilaṣitārthacintāmaṇi* and *Śivatattva-ratnākara also* are some of the texts which deal with the art of painting, colours, mixing of colours, preparation of pigments etc. All these texts treat the subject more or less in a similar manner without much variation.

A *citraka* or *citrakāra*, an artist should have perfect knowledge about different colours and know the use of proper colours in the paintings and he should take great care in mixing different colours.[18]

It is said that fresh buffalo hide should be boiled with water. When sticky butter-like paste is formed, it should be made into small pieces and dried till the pieces become hard. This is called *vajralepa* or adamantine which is very useful for painting in two ways - to prepare the coating for the surface to make it smooth and flawless for painting pictures and to prepare the vehicle or media to mix the pigment for painting. Pigments of different colours have to get suspended sometimes with additives so that they could be used as paints. Hence it is said that the above mentioned pieces of *Vajralepa* should be placed in strong mud vessel filled with water and then heated. When they get melted they may be added to any colouring pigment proportionately to get a particular desired shade. Adding soft white sand and conch powder to this *vajralepa*, the wall or the surface should be smeared with this paste and allowed to dry three times till it becomes smooth and glossy. Then the moon-white mineral called *nāga* found in Nilagiri, embedded in rock should be mixed with this *vajralepa*. This mixture should be applied on the surface of the wall slowly and gently. The wall then becomes ready for painting beautiful pictures (*Śiv. R.* VI.2.10-18).

From the recipe of *vajralepa* given above we can gather that the technology of surface painting and wall painting in different colours was advanced and that people were efficient in selecting and preparing the proper vehicle also for the pigments. Conch powder and a special white mineral called *nāga* found on the Nilagiri were used for preparing white pigments.

Different methods of preparing this *vajralepa* paste are given in different treatises (*Vi. Pu.* III.40; *Sam. Sū.* 72; *ŚR.* 46.131,132; *Bṛh* S. Vajralepa lakṣaṇādhyāya 1-3, 5-8.).

Generally six primary colours are mentioned in the ancient texts. They are white, red, yellow, blue, green and black (*ŚR.* 64.27; *Vi. Pu.* III.27.8; *Śiv R.* VI. 2. 33, 34). *Sveta* (white), *śona* (red), *pīta* (yellow), *kṛṣṇa* (black), *nīla* (blue), *harita* (green). The use of conch powder is recommended for white colour.

Three kinds of red colour are distinguished and they are *śona*, *rakta*, and *lohita*. *Darada* (red lead) is advised for reddish brown, *ālaktaka* (red sap) for blood red and *gairika* (red chalk) for dark red. *Haritāla* (yellow orpiment) is prescribed for yellow colour and *kajjala* (lampblack) for black colour.[19]

Miśravarṇa or mixed colours are also enumerated in some of the texts which are attained by mixing two or three colouring materials or pigments. Red lead mixed

with white conch powder gives the colour of red lotus. Red lac mixed with conchpowder gives the colour of *boraśva* (golden brown). Honey colour is obtained by mixing red chalk with conch powder. *Haritāla* and *śaṅkha* were mixed to give the shade of *boraśva*. Lampblack with conch powder gives a smoky grey colour. Indigo (*nīlī*) mixed with conch white gives pigeon grey colour. *Rājāvarta* with conch powder gives the tint of *atasīpuṣpa*. Indigo with yellow orpiment becomes green. Red chalk when mixed with yellow orpiment becomes lighter in shade. Lampblack mixed with red chalk takes a darker shade. Lampblack with lac attains pink colour and with indigo attains violet colour (*Śiv. R.* VI.2. 35-41).

Probably all these pigments were locally prepared and were easily available in those days.

Metals like gold and silver were also used as colouring materials. The method of preparing gold pigment is mentioned. Gold ore should be pounded well on a stone and adding water to it in a glass container or in a bronze one, it should be shaken slowly again and again. While shaking, the water should be removed by stages until all the dusty particles are removed.

Finally, only the gold dust will remain in the container because of its weight. This paste of gold should be mixed with the *vajralepa* and should be used to paint ornaments and other decorations in the picture (*Śiv R.* VI.2.48-52; *ŚR.* 45.123-30).

In all these texts dealing with the art of painting, the term *vartika* is used which generally means a brush or pencil. But in these texts they are used to connote a crayon or pastel for drawing. We come across the words *tindukavarti* and *kiṭṭavarti* with which the outline of a picture is drawn and they are distinguished as a twig of a special variety of ebony and a black secretion with carbon and prepared as a roll or pastille or *varti* for sketching (*Śiv. R.* Vi.2.28).

Surface coatings

There are references in many of our ancient texts to prove that paints were used as surface coating to walls, pillars, etc. (*Śiv. R.* VI.2.2-4)

A paint meant for surface coating also is a mixture of opaque solids dispersed in a liquid medium which is used as a protective or decorative coating for surfaces which dry up by the oxidation and evaporation of portions of its components. Hence as paints are mechnical mixtures, the pigments and extenders are carried or suspended in the vehicle. The vehicle also should be a film- forming oil to which other liquids are added in varying amounts (Shreve, p.495). Hence the technique of preparing pigments from different colouring agents involved an arduous process of selecting suitable diluents or thinners, vehicles, etc. Moreover, specific requirements of the paints had to be taken into consideration such as colour, hiding (obliteration), weather resistance, washability, gloss, metal anti-corrosive properties and consistency as related to the mode of application like brushing, dipping etc. No doubt, people were highly skilled in these techniques as it is clear from several descriptions of painted walls, *śikharas* and *gopuras* or palaces and mansions in many literary texts.

Colouring Agents

Some of the main colouring agents and ingredients that were used in ancient India are as follows:

Vegetable sources

Indigo has remained a very popular dye ever since the early days to obtain blue colour in different shades. Even in the ancient period, indigo was an important substance of export from India to Egypt, Greece and other countries. Since it is popular and was widely used all over India it is known by several names - nīla, nīlī, nīlikā, etc. In *Atharvaveda*, we get the terms *kāla* or *asikni* (*AV*, 1.233.1; 1.24.1-4).

In the ancient period the plants were thrashed and stored. In course of time the leaves change colour from green to blue grey. Then they were macerated in water and dye was extracted. The *modus operandi* of extracting dye from indigo vary from place to place.

Indigo was primarily used for dyeing cloth blue. By adding different colouring materials in different proportions and sequences, different shades were obtained. Generally, turmeric, saffron, lemon, etc. were added to get colours like watery blue, greyish and sky blue, blue-black, dark blue, light blue, purple, lavender, mauve, lilac, emerald blue, blue-green etc.

Generally the colour was fixed by some mordanting agent like sulphate of iron, carbonate of soda, sugar, etc.

Mañjiṣṭhā or maddar (*Rubia tinctorium*) is mentioned often in almost all ancient texts and seems to have been a very popular dye ever since the period of Harappan civilization. It is even known as the dyer's root. This is a perennial plant and the bulk of pigment is contained in the red mass of the fibrous root. The ancient Indians were adept in the technique of removing the colouring material from the roots which is said to be a complicated one. Alum (*tuvarī, saurāṣṭrī*) was the mordant used to fix the red colour of *mañjiṣṭhā* on cloth.

Turmeric or *haldī* is rich in yellow dye. It has a dull, waxy, resinous fraction and its thick roots when ground produces a bright yellow powder that was used for dyeing. Compounded with other ingredients and mordants, the colour varies from light yellow to orange. The colour remains very fast and produces different shades. In ancient times, as it is now, turmeric is considered to be very auspicious and clothes of the brides and grooms were dyed in this colour. The threads meant for special religious rites were dyed in this colour. Turmeric powder was used (as today) in cooking to give slight colour to the dishes prepared and also in *Raṅgoli*.

Brown colour was also used widely in ancient India. This was obtained from the bark of *babul* (*Acacia arabica*), *catechu* (*Acacia catechu*) and henna (*Mehndī*). The babul bark produces shades of brown by simply boiling in water. While the water is still boiling, by adding *catechu* and lime, a somewhat permanent dye was produced. By adding sulphate of iron, a black dye was produced. Both the bark and leaves of babul tree possess tinctorial properties for which they were frequently used in dyeing industry in ancient and medieval India (Jaggi, I p. 203)

Safflower (*kusumbha - Carthamus tinctorius*) which contains an oil producing seed and a dye which produces a rich shade of rose pink was also widely used all over India. It contains water soluble yellow and water insoluble red components, the two producing an orange hue. When combined with other flowers like *harsingār* (*Nyctanthes arborist*) it gives deep orange, gold orange and salmon colours. *Al* (*Morinda tinctora*) which is grown extensively in North India has its colouring substance in the bark of the root rather than the stem. It was used for printing designs on textiles, mixed with linseed oil. The bark of the *lodhra* tree (*Sympolocas racemosa*) which yields a crimson dye was used for dyeing silks. Sappan wood (*Caesal pinia*), a reddish wood yielding red colour was compounded with acid and alkali to obtain yellow and violet colours. *Kuṣṭha* (*Costus speciosa*) is a well-known plant of the Himalayas. Its leaves which yield a colour of bright gold were used as one of the ingredients in colouring copper (*Dhātuvāda*, 12; Ray, p. 146).

Besides these colouring materials of plant origin, rinds of pomegranates, pulps of wood apples, flowers of *kiṁśuka*, *aśoka*, *harśingār* (*Nyctanthes arborist*), *dhao* (*Grislea tomentosa*), saffron, seeds of *tun*, tamarind, mango, juice of grapes, *jambu* fruits, molasses, and resins, *dhāk* (*Bhutea frondosa*), burnt coconut shells, burnt twigs of special trees, rice flour, etc. were also widely used in preparing dyes and pigments for various purposes. Extracts of some of them were used as binders, vehicles etc. for the pigments. Extracts of myrobalans, betel leaves, *asana kusuma* and *asana kaṣāya*, *mardayantī*, *kakubhaphalam* (*Arjuna*), *hiṅgula* (minium), gall nuts, ink nuts etc. may also be added to the list of colouring agents of vegetable origin.

Dyes of Animal Origin

Among the dyes of animal origin, lac dye (*lākṣā*) was widely used. It is a resinous incrustation formed on the bark of trees by lac insect (*Tachardia lacca*). Two types of lac dyes are shell lac and stick lac.

Bee wax (*madhucchiṣṭam*) was also used as a vehicle of medium for different dye-stuffs. Cochineal is an insect which produces red dye. Kermes (Coccus) which have been yielding a scarlet dye was widely in use in ancient India. This insect is known as *rudhirakrimi* because it originates in blood, particularly human blood. The insects are squeezed with some auxiliaries to produce dye substances for colouring textile fabrics.

Conch shells and even corals were powdered and mixed with some glue for preparing white colours or pigments for painting. Elephant hides, buffalo hides were used to prepare *vajralepa*, a vehicle to carry the pigments. *Madhu* (honey), oils, resins, *guggula* (a fragrant gum resin) etc. were used as ingredients in the compounds of metal solvents and also as binders.

Mineral Substances

Among mineral substances red ochre (*gairika*) which produces red colour for dyeing was well-known in ancient India. Two types of red ochres are mentioned. *Pāṣāṇa gairika* is a hard copper coloured substance while *svarṇa gairika* is a softer one of the deep red colour (*Śiv. R.* VI. 23.108-109). This is grouped under the

uparasas. Red ochre was the most widely used mineral pigment. The term ochre refers to a large class of natural pigments with colours varying from red to yellow, consisting essentially of hydrated iron oxides, often diluted with clay.

Haritāla or yellow orpiment was used for obtaining yellow colours. This is also a *uparasa* according to the ancient texts on Alchemy. It is of two kinds, of leafy structure and in the form of balls or cakes and is of golden colour (*Śiv. R.* VI.23.110-111).

Kāsisa (sulphate of iron) is of two kinds *vālukā* and *puṣpa*. The former is of green variety and used in dyes, particularly in hair dyes. *Manaḥśilā* (Realgar) is of three kinds *śyāmala* of dark red colour, *karavīraka* of golden colour, *manda* in the form of powder of deep red colour. *Sasyaka* is a mineral found in five varieties of colours and is said to impart colour to minerals.[20]

Añjana or collyrium is also of five kinds *sauvīrāñjana, rasāñjana, śrotāñjana, puṣpāñjana* and *nīlāñjana*. The extracts of these *añjanas* were used as cosmetics to the eyes (*Śiv. R.* VI,23; 115.116).

The process of manufacturing *sindūra* is given and four types of *sindura* are mentioned in some texts. *Vasanta kusumākara sindūra* has the colour of *campak* with some fragrance, is soft and delinquiescent. The other three types are *rājamṛga, bhūpati, pūrṇacandrodaya* with the shades of *brhati* flower, *atasī* flower and pomegrenate flower respectively.

Giri sindūra (red lead) is described as found in the form of crest of anthills and when broken, has a tinge of blue lotus and on rubbing it yields red colour[21]. It is found in mountainous regions and is a sort of powder or dust found inside stones (*Śiv. R.* VI.23.112,113). For using *sindūra* as colouring matter it was treated with Realgar (*manaḥśilā*).

Some of the other mineral substances that were used in ancient and medieval India for dyeing and colouring purposes were *rājāvarta* (Lapis Lazuli), *rasaka* (calamine), ferric oxide (minium), *sudhā* (lime), yellow ochre, *trapu* (lead), *kankuṣṭha*, blue vitriol, etc. Three kinds of *hiṅgula* (vermilion) are mentioned as useful in medicine, in colouring metals and in colouring mercury. The three kinds are: *camara* of very deep colour, *śukatuṇḍa* of slightly yellowish tinge and *haṃsapāda* of the colour of birth red *japākusuma* and this type is considered the best.[22] *Rajāvārta* is slightly red at centre with a bluish tinge.

In texts like *Rasaratnasamuccaya, Rasasiddhāntaśāsanam* also we get information about mineral substances used for dyeing and colouring.

Conclusion

The particulars given above reveal that the people in ancient India and even those of the pre-historic Age were using different kinds of dyes, mordants and pigments to colour textiles and to paint potteries, surfaces of wall, pictures etc. Most of the colouring substances were obtained from vegetable products and also from minerals which were easily available in and around their own settlements or villages and sometimes obtained from other regions. People knew the use of mordants also

to fix the dyes on cloth especially cotton. During the Tantric period metals were also used as pigments to coat or paint surfaces like that of pillars and walls. The above accounts strongly testify to the fact that India was not lagging behind in her technological activities. Dyeing and painting developed in ancient India as a rural technology. Eventhough the country was not industrialised as it is today, but still cottage industries, particularly those related to dyes, pigments and paints flourished and each region followed its own technique depending upon the availability of colouring substances, geographical and climatic conditions.

By the early centuries of the Christian era, the art of dyeing cloth in India had become proverbial. This is indicated by a reference in St. Jerome's translation of the Bible, made in the 4th century, where Job says that wisdom is more durable than the 'dyed colours in India'.

Indians had mastered the complicated techniques of dyeing cotton which was not the superficial use of pigment but involved permeation of the fibres (Munroe, pp,25-26; quoted in Jaggi, I,p.210). Such statements, no doubt, speak a lot about the perfect skill exhibited by ancient Indian people in preparing and using dyes, mordants and pigments for beautifying the entire surroundings.

Notes

1. *cakṣurmātragrāhyaḥ guṇaḥ rūpam/(Tar of Annāmbhaṭṭa)*
2. *rajake kaścidāyāntam raṅgakāram gadāgrajaḥ/drṣṭvāyācata vāsāṃsi dhautānyatyuttamāni ca (Bhāg. Pu, X.41.32; Bra.Pu. 187.4).*
3. *nīlanī kṛṣṇavarṇāni dhūmrāṇi madhurāṇi ca pāṭalānyabhirā māṇi jambūphalanibhani ca nānāvarṇa vicitrāṇi nānārūpa mayāni ca madhye raktāni kṛṣṇāni pītāni haritāni ca (Śiv R. VI. 16.13-15)*
4. *mañjiṣṭhārāgayuktāni lākṣārāgayuktāni ca kusumbharasayuktāni sindūrāruṇakāni ca (Śiv.R VI 16. 18-19)*
5. *tuvarī mañjiṣṭhā rāgabandhinī (Ray, p. 103)*
6. *saurāṣṭrakhanisambhūtā mṛtsnā yā tu varā matā vastre tu lipyate ya sa manjiṣṭhā rāga vardhinī pītikā sphuṭikā ceti dvidhā sā parikirtitā īsat pītā guruḥ snigdhā pītikā viṣanāśinī (Śiv.R. VI. 23.103-104)*
7. *saurāṣṭradeśe sañjātā khanijā tuvarīmatā yā lepitā śvetavastre rangabandhakari hī sā pullikā khaṭikā tadvat dviprakāra praśasyate (RPS of Yaśodhara; Ray, p. 358; RRS, II.59-62)*
8. *netrayorāñjanam kāryam adharasya ca rañjanam dantānam vividhā rāgāḥ caturṇām śuklata yatha (Nāṭ* of Bharata, *21.28, 40,41; Ṛts* of Kālidāsa, *1.5, Kād, p.11)*
9. *nakharañjako nāma vṛkṣaviśesa yasya piṣṭaiḥ patraiḥ nakhānam rāgam striyaḥ utpādayanti patram ca dadyāt mada yantikāyāḥ lepo'ngarāgo naradevayogyaḥ iti suśrutah (Vaidya, 1936, p.418)*

10. *mañjiṣṭha kuṅkumam lākṣā khadiraścāsanam tathā rakta vargastu deveśi pītavargamataḥ śṛṇu kusumbham kiṃsukam rātrī pataṅge madayantika (Rnv, 5th Paṭala, Oṣadhinirṇayaḥ, 39)*

11. *nikaṭavartinaḥ tamālapādapāt pallavamādaya niṣpīḍya tataśilātale tena gandhagajamadasurabhi parimalena rasena uttarīya valkalaika-deśād vipāṭya paṭṭikām svahastakamalaka niṣṭhikā nakhaśikhareṇa abhilikhya iyam patrikā (Kād* of Bāṇa) *nīlīrāga mecakarucā caila cīrikayā racita muṇḍamālikām (Hṣa* of Bāṇa, *p.133)*

12. *rasāyane sarvarogaharaṇe loharañjane sūtasya rañjane śreṣṭho varṇotkarṣakarmaṇi (Śiv R.VI. 23.127).*

13. *tīkṣṇam nāgam tathā śulvam rasakena tu rañjayet samastam jāyate hema kūṣmāṇḍakusuma prabham (Rṇv. VII.50)*

14. *rūpabhedapramāṇāni bhāvalāvaṇyayojanam sādṛśyam varṇikā bhaṅgam ṣaḍete citraabhagakam (Vāt.)*

15. *mūlaraṅgāḥ smṛtāh pañca śvetapīta vilohitaḥ kṛṣṇo nīlaśca rajendra śataśo'ntarataḥ smṛtaḥ (Vi. Pu, III. 40, 16-24)*

16. *raṅgadravyāṇi kanakam rajatam tāmrameva ca abhrakam rājāvartam ca sindūra trapureva ca haritālam sudhā lākṣā tathā hiṅgulakam nṛpa nīlam ca manujaśreṣṭha tathānye santyanekśaḥ (Vi Pu. III. 40,25,26)*

17. *kuṃkumapiñjaritapṛṣṭhasya caraṇayugalasya (Hṣa, p.31) kusumbharāgapaṭalam pulakabandhacitram (Hṣa,p.32) manjiṣ ṭha rāgaiohite kiraṇajāle (Kād p.53) āmattakokila locanachaviḥ nīla paṭalaḥ kaṣāya madhuraḥ prakāmapīto jambūphalasāraḥ (Kād,p.36) gorocana kapiladyutiḥ (Kād, p.126) haritāla kapila pakva veṇu vitapa racita vrittibhiḥ (Kād, p.392)*

18. *vidvadbhiḥ manakuśalaiḥ citralekhana kovidaiḥvarṇapūraṇa dakṣaiḥ ca miśraṇe ca kṛtaśramaih (Śiv. R. VI.2.8)*

19. *śveteṣu pūrayet śanham śoṇeṣu daradam tathā rakteṣu ālaktakarasam lohite gairikam tathā pītesu haritālam syātkṛṣṇe kajj alamiṣyate (Śiv. R. VI.2.33, 34)*

20. *kāsīsam renukadyekam puspapūrvamathāparam kṣārabam guru puṣpādyam soṣṇaviryavisapaham valukapurvakam tatra viṣaghnam keśarañjanam (Śiv. R. VI.23, 98, 99,; RRS II.51)*

21. *valmīkaśikharākāram bhaṅge nilotpaladyutim gharṣaṇe raktava ṛṇam syāt sindūram tatpraśasyate (Śiv R. VI. 22. 109-112).*

22. *carmārastīkṣṇarūpaḥ syātsupītaḥ śukatuṇḍakaḥ japakusuma saṅkāśo haṃsapādo mahottamaḥ rasāyane sarvarogaharaṇe loharañjane sūtasya rañjane śreṣṭho varṇotkarṣakarmaṇi (Śiv. R. VI. 23, 124-127)*

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Surgical Techniques

AKHILA NAND SHARMA

Introduction

Hindus believe the existence of Indian Medicine to be of divine origin. Lord Brahmā, the first member of god triad (*Trideva*), was the profounder of Ayurveda, the science of life. There is vivid description of Ayurveda in *Ṛgveda* and *Atharvaveda*. Divodās Dhanvantari was the direct disciple of Indra and he preached his scientific knowledge pertaining to surgery to his disciples, particularly addressed to *Suśruta*. In classical age, ancient surgery was considered the most important and significant branch of Ayurveda. In the mythical of Ayurveda itself, ancient surgery was accorded the first place and headed amongst the eight divisions of Ayurveda.

The vast medical literature of ancient India practically remains as yet unexplained, and any undertaking, which has the object of making that terra incognita, known to the scientific world, is bound to be welcomed by the public. The west, until the close of the eighteenth century, remained ignorant of the achievements of the ancient Hindus in art, science and culture.

The treatise of *Caraka* and *Suśruta*, as revised and redacted by the later Hindu philosopher - physicians of the Ayurveda, was entitled to a great respect, and was associated with the *Atharva Veda* in a special way. The work of 'Suśruta' is one of the greatest of its kind in Sanskrit literature.

It is especially important from the surgical point of view and to him to be contributed the glory of first changing the art of surgery into a practical science, during the Vedic Period. It seems that from time to time many hands were in operation or what passes on as the *Suśruta Saṃhitā* today and the available evidence points out that the original treatise of Vṛddha Suśrutā, the *Suśruta Tantra*, was a different work and formed the basis of the Saṃhitā, which was probably entirely revised, at a later date, by another author, also called 'Suśruta' by name, and again enlarged and supplemented by Nāgārjuna in the second century B.C. The original Tantra, according to A.F.R. Hoernle (1907), indeed admittedly belongs to a much earlier period, possibly as early as about 1000 B.C. Hessler (1844) who edited

Suśruta Saṃhitā in Latin language, also places Suśruta during the heroic age of India, though the beginning is not known but the end of which is marked by the 1,000 years B.C. The other European scholars like Lietard (1863), Dymock (1870), and Max Neuberger (1901) have mentioned various dates to Suśruta, ranging from the first century A.D. to the tenth century A.D. Considering all the evidence available today, one comes to the conclusion that, the "lower limit of Suśruta's death is fixed" as the sixth and seventh century B.C. This being the date of *Śatapatha Brāhmaṇa*, while practically nothing can be said about the upper limit (Das Gupta, 1932).

Definition and importance of Śalya (ancient surgery)

Śalya is the name applied to the art of surgery in Indian Medicine and is derived from the root *Śal* or *Śval* meaning to move quickly. Foreign bodies of every kind are denoted as *Śalya*, but it specifically refers to the arrow, which was the commonest and most dangerous foreign body causing wounds and requiring surgical treatment during the Aryan invaders, and surgeons were directly requisitioned to attend on the wounded.

The *Śalya Tantra* or the science of surgery is the oldest of all the other branches of the science of Indian Medicine (Ayurveda) and is further corroborated by the four classes of testimonies, i.e. perception, inference, analogy and scriptural truths. The primary position of ancient surgery may be inferred from the fact that surgery lands her aid materially towards the healing up of traumatic ulcers. Moreover, Indian surgery (*Śalya Tantra*) is considered to be the most important as instantaneous actions can be obtained with the help of surgical operations, external applications of caustics, cauterisation, blood-letting, etc. Secondly, it contains all that can be found in the other branches of the medicines as well. It is eternal and is source of infinite piety, imparts fame and opens the gates of Heaven to its voteries, prolongs the duration of human existence on earth and helps the human beings in successfully fulfilling their missions and earning a decent competence in life.

It has always been a matter of speculation how the ancient surgeons ever performed the major surgical operations successfully in the absence of anaesthesia, haemostatics, antiseptics and antibiotics.

However, the knowledge of anatomy was requisite to them as evidenced by the concept of *marmas* (vital points) based on regional anatomy. The ancient surgeons were quite aware of the infections following surgical operations and they extended top priority to prevent it.

The clinical approach and major surgical operations i.e. peptic ulcers, perforations and paracentasis, etc. mentioned by Suśruta, the father of Indian Surgery have opened a new avenue to modern surgery. The scientific approach to perform rhinoplasty as well as otoplasty pertaining to plastic surgery in 6th century B.C. had been appreciated by the modern surgeons. Herschberg of Germany mentions that "Our entire knowledge of plastic surgery took a new turn when those cunning devices of India war became known to us."

Thus, in *Ṛgveda*, we read of the amputations of legs and fitting with artificial limbs, extraction of arrow from the limbs of the wounded, and enucleation of eye and corneal grafting with great success.

The most outstanding performances of Indian surgery, however, were on a domain of transplantation of organs, plastic surgery, urolithotomy and laparatomy, etc. Divodās Dhanvantari recites an incident which took place in one of the wars of the gods. Rūdra chopped off the head of the Yagna, then on the request of the gods the Aśvinī brothers (twin) undoubtedly reimplanted the head of the Yagna to the trunk successfully and restored him in life.

In another instance, the head of Dadhicī was cut off and the head of the horse was transplanted to him. Later on, the original head of Dadhicī was reimplanted to him after removing the head of the horse. It is an excellent example of heterotransplantation. It clearly indicates that the transplantation surgery was highly developed and practised in ancient India. There are several other instances where severed parts of the human beings were transplanted with success.

Once, the wife of king Khela named Vispala had lost one of her legs in the war. The Aśvinī brothers provided her with a metal leg (artificial limb). The father of Rijashva became blind as a result of cursing, and the corneal grafting was successfully carried out to restore his normal vision. The broken teeth of Puśan were restored as normal. Moreover, the Aśvinī brothers demolished all the diseases of the gods and gave them young life. Suśruta was one of the matured and most knowledgeable pupils amongst other several disciples of Divodās Dhanvantari. Therefore, he imparted his scientific knowledge to Suśruta. Moreover, the training of surgeons, meticulous code of personal ethics, and the social conduct for the medical profession in general, have touched the highlight of Suśruta's contribution. These are some of the topics which are not generally included in the modern surgery, and hence it would be of interest to the surgeons to know more about these important matters for improving their services to the humanity as a whole.

It is generally accepted that Suśruta's lucid and systematic presentation of the conceptual and technical aspects of surgery, as well as the philosophy and ethics of medicine was quite advanced and may have relevance even to-day (Thorwald).

Surgical Armamentarium of Susruta

Status of surgery of any period can be best evaluated by variety and quality of the surgeon's armamentarium. Suśruta has mentioned 101 blunt and 20 sharp instruments which could be the precursors of modern surgical instruments. Virtually, number of them have similar names such as *siṅghmukha yantra* (lion forcep), *mudrika sastra* (finger knife), etc. Varieties of needles (straight, curved or round body, blunt and cutting), suture materials, splints and fracture bed for immobilization of fractures at various sites, fourteen different types of bandages and parasurgical measures, i.e. cautery, etc. for checking the bleeding are further examples.

Moreover, Suśruta has further mentioned the specific use of some instruments needed for the specific surgical manoeuver, such as endoscopy to visualise the haemorrhoids and fistula-in-ano and *mudrikā śāstra* (finger knife) for conducting blind surgical procedures in the case of retropharyngeal abscess or removal of the dead foetus through vagina.

Surgical Concepts of Suśruta Saṃhitā

Suśruta has scientifically classified in a systematic way the clinical material and the fundamentals of management which are valid even today. Classification of traumatic wounds their prognostic evaluation as well as management, suturing in clean wounds, avoidance of sepsis, and careful suturing of intestinal perforation etc. are highly remarkable. However, he was the first to recognise the basic pathology of thermogenic injuries hot or cold.

Clinical Surgery by Suśruta

The clinical approach and surgical treatment of certain abdominal disorders mentioned by Suśruta have given a new light to modern surgery. The management and surgical treatment of perforation of intestines mentioned by Suśruta in such an excellent way that it is being followed by the modern surgery, as well as the description pertaining to intake of blood seemed to be rational and scientific. In addition, Suśruta has given a clear description on paracentasis of abdomen in cases of ascites. After the complete outflow of the fluid, the abdomen should be firmly tied with a many tailed bandage in order to prevent further accumulation of fluid. In modern surgery too, the same surgical approach has been described, which affirms the value of the ancient surgery. The ancient method of surgical approach to remove the urinary calculi appears to be in no way different as worked out at the present era by the modern surgeons.

Moreover, Suśruta has described various means of exiting the blood to cure a number of diseases. Thus, cupping, application of leeches, blood-letting in various forms were wide spread methods of treatment in many major diseases, i.e. high blood pressure, sciatica, and several other nervous ailments. It was most common during the ancient era and more than fifty percent of the diseases of the human being were cured by venesection(*Śirā Vedha*) or blood letting.[1]

Major surgical operations were carried out during the period of Suśruta, without anaesthesia. The most infrequent successful outcome of such operations, done regardless of all antiseptic precautions, could only be explained by the supposition that the aboriginal races had a greater power of resistance against wound infection than highly civilised nations. Moreover, the fumigation of operation theatre by guggulu and other similar indigenous drugs have been mentioned by Suśruta to prevent the infection in surgical cases. However, the modern surgery follows the same pattern of distempering the operation theatres these days. Surgical operations used to be performed on an auspicious lunar, day, star and movement after worshipping the god of fire, Brāhmins, physicians, with curdled milk, rice, drinks and jewels and after offering presents as well as blessings. Suśruta mentions three stages in the treatment of surgical diseases, i.e. the preliminary measures (*pūrva-karma*), the principal/surgical performance (*pradhāna-karma*), and the post-operative management (*paścāta-karma*). Great emphasis is being laid on the post- operative measures, caustic was considered superior to all cutting instruments. Fire (*Agni*) as well as cauterisation (*Agnikarma*) was regarded even more efficatious

than the caustics. It was mostly used to erradicate the tumours, fistulae, elephantasis and haemorrhoids, etc.

Similarly, the use of alkalies prepared in three strength, weak, medium and strong, was practiced for external and internal applications. External application was advised in all sorts of skin ailments, haemorrhoids, fistula-in-ano and other fistulae as well; internally they were used for poison of lingering effect, swelling of the body, loss of appetite, calculi and internal abscesses etc. At present, they are vastly used by followers of Suśruta in the form of '*Kṣāra-sūtra*' (alkali braided thread) for the treatment of fistula-in-ano cases with excellent results. Moreover, the recurrence of the disease following the use of *Kṣāra-sūtra* is very minimal.

Splints

The barks of several latex trees, i.e. *madhuka, udumbara, aśvattha, palāśa, kakubhā, bamboo, sarjā* and banyan were used for the purpose of splints. It used to solve double purpose, the first as an antiseptic in cases of compound fractures and second, the soothing affect alongwith immobilization of the part.

Plastering

A moderately firm bandage has been advised for optimum immobilization following the local application of certain indigenous medicines, i.e. *manjiṣṭha, madhuka*, red sandal wood and *śāli* grain (rice variety) powder mixed with a hundred times washed clarified butter (*ghṛta*). This application of plaster helps to promote the union of fracture ends of the limb as well as combates the infection. Moreover, four methods of fracture reduction have been mentioned, traction, pressure, aposition and bandaging.

Specific management of subungual haematoma, fracture of the toes, and fingers, bones of the hands and feet, humerus, femur, ankle, wrist, pelvis, ribs, naval bones, and skull fracture have been described. The fracture bed (*Kapāṭa-Śayan*) has also been advised in the case of the fracture of the neck of the femur for complete immobilization of the part, which is considered the unique contribution of Susruta as appreciated by the modern surgeons. Similarly the specific management of the dislocations of the hip, shoulder, the elbow, knee, ankle and wrist, the neck and the jaw have been described in a scientific way.

Methods of treatment for piles and fistula-in-ano

There are four methods of treatment for piles. They are medicinal treatment, caustics, fire or cautery and surgery. Out of them, the piles which have a narrow pedicle, are projecting and moist should be treated by surgery. The soft, extensive, deeply situated and projecting ones are curable by caustic treatments while rough, firm, thick and hard ones are curable by fire cautery.

Technique

Surgical operation - A large pile mass having a narrow pedicle, moist and projecting, should be treated by surgery.

Pre-operative - The patient suffering from piles should be oleated and sudated. He should then be made to sit in a covered and clear place in modern climatic condition, on a clear sky day and on a flat plank or on a bed. The anus should face towards the sun with the patient in the supine position, and the upper part of his body held in someone else's lap.

The waist should be raised a little higher. The neck and the legs should be fixed firmly by a strap and held firmly by assistants. Thereafter, his anus should be lubricated with *ghṛta* (clarified butter) and a sterilized well lubricated rectal speculum should be introduced in the rectum along its passage slowly while the patient is straining.

Thus, the piles should be visualised and examined properly by the surgeon and the projecting pile mass should be clipped off with a knife and cauterized with fire to prevent bleeding. Thereafter, the pile mass should be mollified by the application of *ghṛta* mixed with *madhuka* and the instrument should then be taken out.

Post-operative - Following the surgical operation, the patient should be made to get up and sit in warm water, whereas cold water should be sprinkled over him. He should then be taken into a room for post operative care with proper instructions.

Technique of caustic application (Kṣāra)

Following the pre-operative procedure as mentioned earlier adopted in the surgical operation, the pile mass should be pressed by a probe, wiped with a piece of cotton swab or a piece of cloth, caustic (*Kṣāra*) should be applied on it. Following this application of caustic, the opening of the instrument should be covered by the hand of the surgeon and should let it remain until the counting of one hundred (approximately one minute). Then after wiping, the caustic may be applied again, taking into consideration the strength of caustic as well as the severity of the disease. The application of the caustic should be stopped when the piles show the color of a ripe *jambu* fruit (Bluish black) and get depressed and shrivelled. Thereafter, the caustic should be washed away by sour gruel, curd, butter milk, vinegar or by the juice of citrous fruits. Then the pile mass should be mollified by the application of *ghrta* or any medicated soothing oil and the instrument should then be taken out.

The post-operative management of the patient should be maintained as described earlier. The remaining pile masses may be treated one by one at intervals of a week each. In case of multiple piles the right one should be handled first; after the right, the left one and after the left the posterior one; lastly the anterior one should be treated in the same fashion. The post- operative management and the dietary regimen should be according to the instructions mentioned by Suśruta.

Fistula-in-ano (Bhagandara)

Surgical technique (General): The patient should be soothed by the application of medicated oil and his body should be fomented by immersing him in a receptacle of warm water. He should be put on a bed, positioned as described for the treatment of piles. The surgeon should examine closely as to where the mouth of the fistula is directed, outward or inward. Then a probe should be introduced carefully while the patient is straining and the fistulous opening located, raised on a probe, and cut by the knife; or else fire cautery or caustics should be used after proper assessment. This is the general surgical treatment for all types of fistulae.

Specific Treatment (Surgical): In cases of the *Śataponaka* type of fistula, the surgeon should connect one fistulous track with another by incising the tissues in between. External fistulae interconnected with one another should be excised separately (not all together). Thus, in a case of *Śataponaka* fistula (fistula having multiple openings), the wound should not be opened wide.

Types of Incisions for Śataponaka Fistula: In a case of aforesaid fistula, the wise surgeon should make *Laṅgalaka* (Plough or T-shaped), *Ardha-laṅgalaka* (T or T like), *Sarvatobhadra* (circular), or *Gotirthaka* (semicircular) types of incisions.

An incision equal to both sides is known '*Langalaka*'; while an incision with one short arm is called *Ardhalaṅgalaka*. An incision encircling the anus except the perineal raphe is known as *Sarvatobhadraka*. An incision made by introducing the knife from one side called '*Gotirthaka*'.

All discharging passages should be cauterized by the fire cautery by the surgeon. The *Śataponaka* type of fistula is difficult to treat in the delicate and the timid.

Post-operative management should be carried out precisely mentioned by Susruta in each type of fistula accordingly. There are five types of fistulae and each of them has its specific management which should be referred to the Suśruta Samhita.

Kṣāra-Sūtra (thread prepared by alkalies): The application of *Kṣāra-sūtra* in cases of fistula-in-ano has commanded wide reputation and W.H.O. has extended recognition to it, considering its supremacy as well as the most simple technique. The chances of recurrences are rare. The patient can carry on his usual duties following the application of this medicated thread without any problem.

Preparation of alkali thread or *Kṣāra-sūtra* - Surgical linen thread size 20 may generally be used for this purpose. This thread is impregnated into the lotion of (*haridrā*) turmeric. Then the latex of *Snuhi* is being applied on the thread and number of coating be done to enhance the activity of the thread. It should be used as fresh prepared or it can be stored carefully keeping away from the moisture. The alkali thread prepared from *Apamārga* and *Ārk* may also be used.

Technique - This prepared thread should be used through a specifically designed smooth, curved needle from the external opening of the fistula and should be taken out through the internal opening of the fistulous track. The surgeon should guard the needle putting his finger in the rectum to protect the rupture of the rectal wall. Then the thread should be knotted moderately and the dressing with *ghṛta* or medicated oil be done. The thread should be changed weekly till the fistulous track

is completely excised. This technique is universally appreciated and adopted. This *Kṣāra-sūtra* is being made available in the market in the sealed tubes.

Management of the urinary calculi

If the urinary calculi are not amenable to the medicinal treatment as described by Suśruta, surgery has to be the ultimate goal. The success is even uncertain in the hands of the expert surgeons, operation should be considered last of all in these cases and it should be carried out by a skilled surgeon, after taking the consent of the authorities concerned.

Pre-operative preparation

The patient should be oleated, his system should be cleansed with emetics and purgatives and be slightly reduced thereby. He should be massaged with oil, sudated, and be made to partake of a meal. Prayers, offerings and prophylactic charms should be offered and the instruments as well as surgical accessories, needed in the case should be arranged in proper order according to the instructions mentioned in the *Sūtra-sthānam* of *Suśruta Saṃhitā* Chapter V and he should be reassured.

Position of the patient

The patient of strong physique and unagitated mind should then be made to lie on his back on the table placing the upper part of his body in the attendant's lap, with his waist resting on an elevated cloth cushion and his knees as well as ankles fixed and tied together by straps.

Manipulation of the Stone

The umbilical region (abdomen) of the patient should be well rubbed with oil or with clarified butter (*ghṛta*), pressure should be applied by a fist below the navel until the stone comes down within the reach of the operator. The surgeon should then introduce into the rectum, the second and third fingers of his left hand duly anointed and with the nails well pared. Then the fingers should be carried upward towards the perineal raphe i.e. in the middle line, so as to bring the stone between the rectum and the penis, when it should be so firmly and strongly pressed as to look like an elevated tumour, keeping the bladder tense and distended so as to obliterate the folds.

Contra-indications to surgery

An operation should not be proceeded with, nor an attempt be made to extract the stone in a case where the patient would be found to drop down motionless (faint), with his head bent down, and eyes fixed in a vacant stare like that of a dead man, as an extraction in such a case is sure to be followed by death.

The operation should only be continued in the absence of such an occurence.

Operative Procedure and Technique (Perineal cysto-lithotomy)

An incision should then be made on the left side of the perineal raphe at the distance of a barley-corn and of a sufficient width to allow the free egress of the stone. Several authorities recommend the incision to be on the right side of the raphe of the perineum for the convenience of the operation. Precautions should be taken so that the stone does not get broken, or crushed. Even if a small particle is left behind it again increases in size; hence, all of it should be removed by the curved forcep.

In females, the uterus is adjacent to the urinary bladder, the incision should be directed oblique and upwards; otherwise a urinary fistula might result from the deep incision in that locality. Any hurt to the urethra during the operation would be attended with the same result even in a male patient.

Post-operative management

After removal of the stone the patient should be put in a tub of warm water and sudated. Thus the bladder does not get filled with blood, however, if it does get filled up, it should be irrigated through a catheter using the decoction of the latex trees.

For the clearance of the urinary passage after operation, a treacle solution should be given to the patient; and after taking him out of the tub, the incidental ulcer should be lubricated with honey and clarified butter (*ghṛta*), the patient should be given warm gruel processed with urine purifying substances and mixed with *ghṛta* twice daily for three days. After three days, milk and treacle and small quantities of well cooked rice should be given for ten consecutive days. Thereafter, citrous fruits and juices prepared from wild animal's meat should be given. After that, for ten days he should carefully be given sudation therapy either by oils or by liquids. Then his wound should be washed by the decoction of latex trees. The medicated pastes of some indigenous drugs should be applied to the wound. A medicated oil or *ghrta* cooked with turmeric and other indigenous drugs should be applied to the ulcer.

Treatment of Impacted Urethral Stones

If seminal concretions or gravels spontaneously coming into the urinary passage get impacted there, they should be removed through the natural passage. If this does not seem possible, the passage should be laid open and the concretions should be extracted by budish instrument (a hook).

After the wound has healed, the patient should neither indulge in sexual intercourse, nor ride on a horse, an elephant, a chariot, or climb a mountain or a tree, for the period of one year; neither should he swim in water nor take heavy meals.

Precautions

The urinary passages, seminal passages, testicular-channels, trigone of the bladder (*Mūtrapraśeka*), perineal raphe, vagina, rectum and urinary bladder should be avoided from injury. If urinary passages are injured death occurs due to the bladder becoming full of urine. If seminal passages are injured death or impotency occurs. If testicular channels are injured loss of erection takes place. Injury to the vagina and the perineal raphe gives rise to severe pain. The features of injury to the urinary bladder as well as the rectum have been mentioned earlier.

Suśruta should also be credited to be the first who described the removal of the stone from the bladder through the perineal route, a method which was still in extensive practice, till the last century. Celsus in 3rd century A.D. described it, but Indians have been practising this method for centuries earlier and it is possible. Celsus may have borrowed it from Indian sources although he has not mentioned it. Suśruta is precise and explicit in describing the operative procedure, the precautions to be taken, complications encountered and the post-operative instructions, etc. which indicate his thoroughness with the technique.

Intestinal obstruction and perforation of Intestines

Laparotomy

Technique - Cases of intestinal obstruction and of intestinal perforation should be oleated, fomented and anointed and then their abdomen should be incised below the navel, four fingers beyond the hairy line (midline) on the left side, and after bringing out the intestines four fingers in length at a time, they should be inspected carefully and the stones, hair balls or faecoliths obstructing the intestines in the intestinal obstruction should be removed. After applying the honey and *ghrta* (clarified butter) the intestines should then be put back in their original position and the external abdominal wound should be sutured in routine way.

Similarly, in cases of perforation of the intestines, after removing the foreign body and cleansing the intestinal discharges, the edges of the hole in the intestine having been brought together should be got bitten by black ants. When the ants have bitten the intestines their body should be chopped off and removed having the heads behind. Then the suturing should be done as before and other reparative measures should also be taken as described earlier. Black clay mixed with *madhuka* should then be pasted and bandaging completed. Thereafter, the surgeon should cause the patient to be removed to a chamber protected from draught and post-operative instructions should be issued. The patient should be made to sit in a vessel full of oil or *ghṛta* and his diet should consist only of milk.

Management of Ascites

Paracentasis : A patient afflicted with ascites (*Jalodara*) should be first anointed with medicated oils, possessed of *vāyu*-subduing virtues and fomented with warm water. He should be made to stand and held firmly in the armpits by dependable persons attending on him. The surgeon should make a puncture with a surgical

instrument known as the trocar (Vṛhi-mukha), on the left side of the abdomen below the umbilicus, to the breadth of the thumb in depth and at a distance of four fingers to the left of the dividing line of hairs (midline) in the abdomen. Simultaneously, with that a metal tube or a bird's quill, open at both ends, should be introduced through the passage of the puncture to allow the morbific fluids accumulated in the abdomen, to ooze out. And then having removed the tube or the Quill, the puncture should be lubricated with oil and salt and bandaged.

The entire quantity of the morbific fluid should not be allowed to ooze out in a single day, inasmuch as thirst, fever, aching of the limbs, dysentery, dyspnoea and a burning of the feet might supervene in consequence, or as it might lead to a fresh accumulation of matter in the abdomen, in the event of the patient being of a weak constitution. Therefore, it should be gradually tapped at intervals of three, four, five, six, eight, ten, twelve, or of even sixteen days. After the complete outflow of the ascitic fluid, the abdomen should be firmly tied with a piece of flannel, silk-cloth or leather, so that gases may not cause distension.

Diet - For six months the patient should take his food only with milk or with the soup of wild animals:

The diet for the next three months should consist of (meals taken with) milk diluted (and boiled) with an equal quantity of water or with the meat soup of animals of the wild group seasoned with the juice of acid fruits. During the next three months it should consist of light and wholesome meals. This rule observed for a year brings about a cure.

Management of the Foetal malpresentation

Craniotomy - In cases where there would be any necessity of using an instrument for the purpose of delivery, the enciente should be encouraged with hopes of life, before making the surgical operation. The head or skull of the child in such cases should be severed with the knife known as the circular knife (*maṇḍalāgra*) or the finger-knife (*Aṅguli-Sastra*). Then having carefully taken out the particles of the skull-bone, the foetus should be drawn out by pulling it at its chest/axillae or at the shoulder with a forcep (*Śaṅku*) of hook type. In case where the head would not be punctured and smashed, the foetus should be drawn out by pulling it at the cheeks or the eye-sockets. The hands of the foetus should be severed from the body at the shoulders when they would be found to have been obstructed in the passage and then the foetus should be drawn out. The abdomen of a child in the womb should be pierced and the intestines drawn out, in event of the former being swollen into a flatulent distension like a leather bag (for holding water), as such a procedure would remove the stiffness of its limbs, and then it should be drawn out. The bones of the thighs should be first cut out and removed, where the foetus would be found to have adhered fast to the passage with its thighs.

In short, whatever part of the foetus gets stuck up, the surgeon should excise it and deliver the foetus fully and protect the woman with all care. (Figs 1-20)

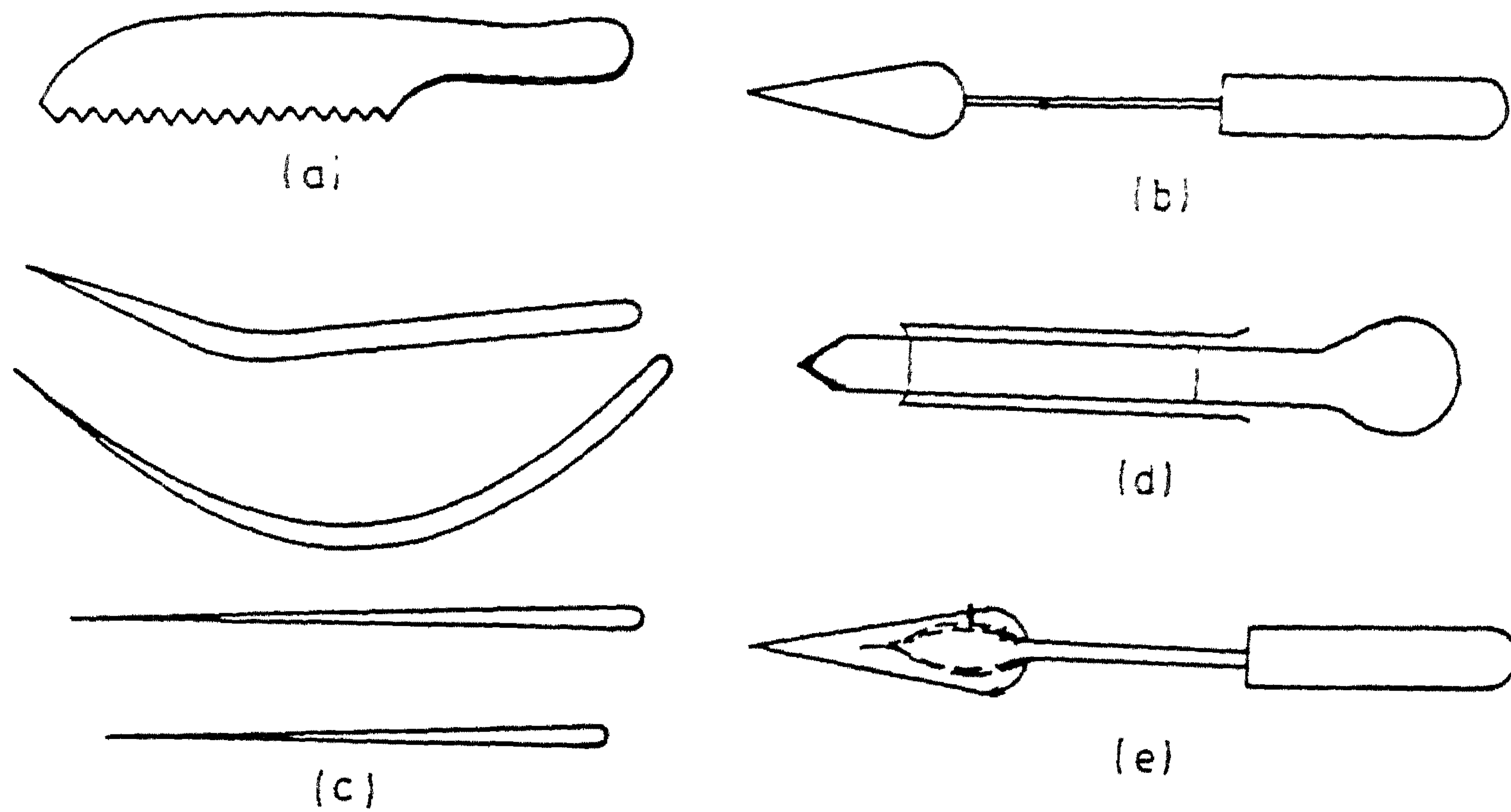


Fig. 1. Some sharp instruments mentioned in Suśruta. a. Karapatra śastra, b. Kuśapatra Śastra, c. Sūci Śastra (needles), d. Trikurcaka Śastra, e. Vetaspatra Śastra

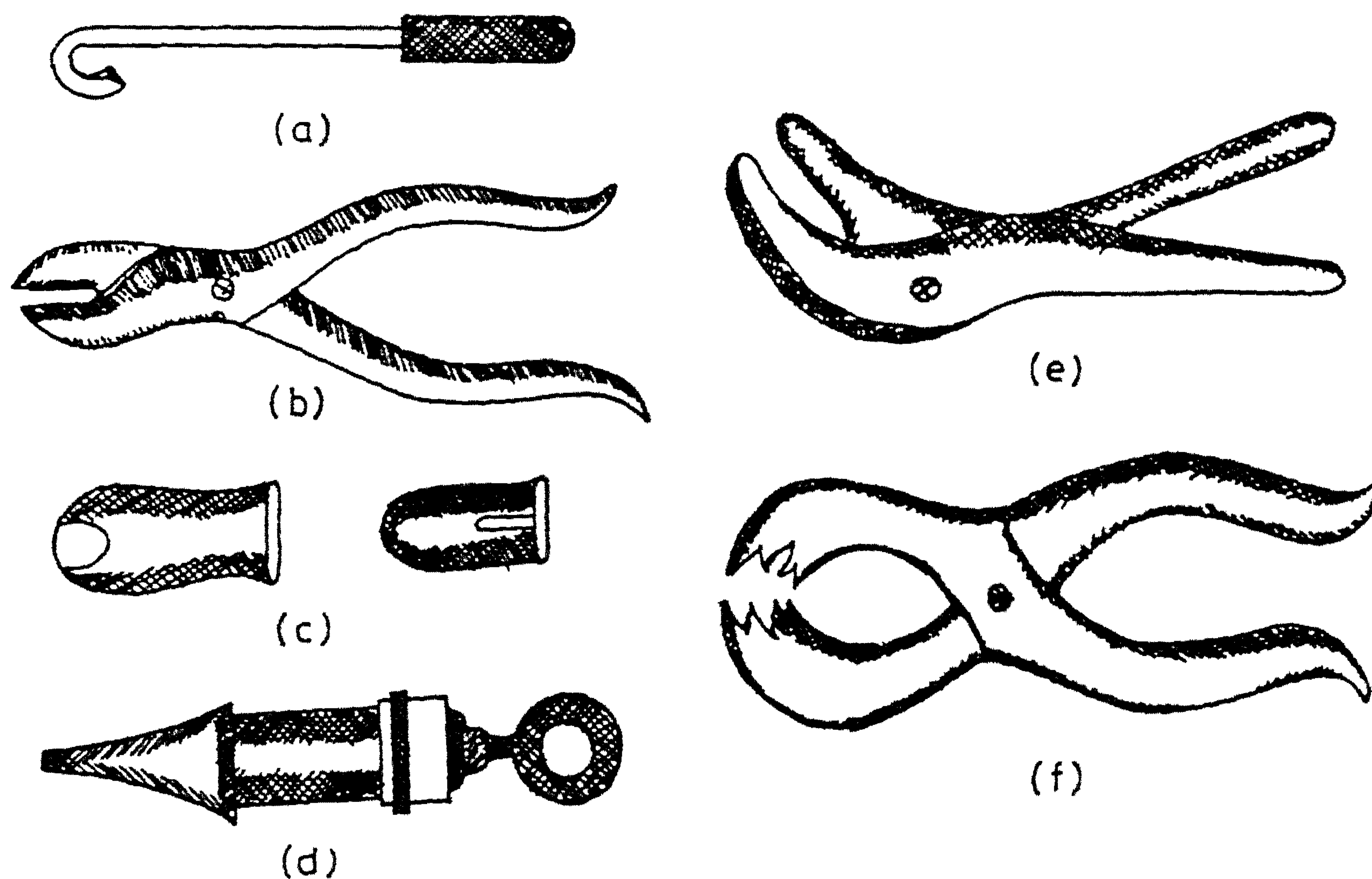
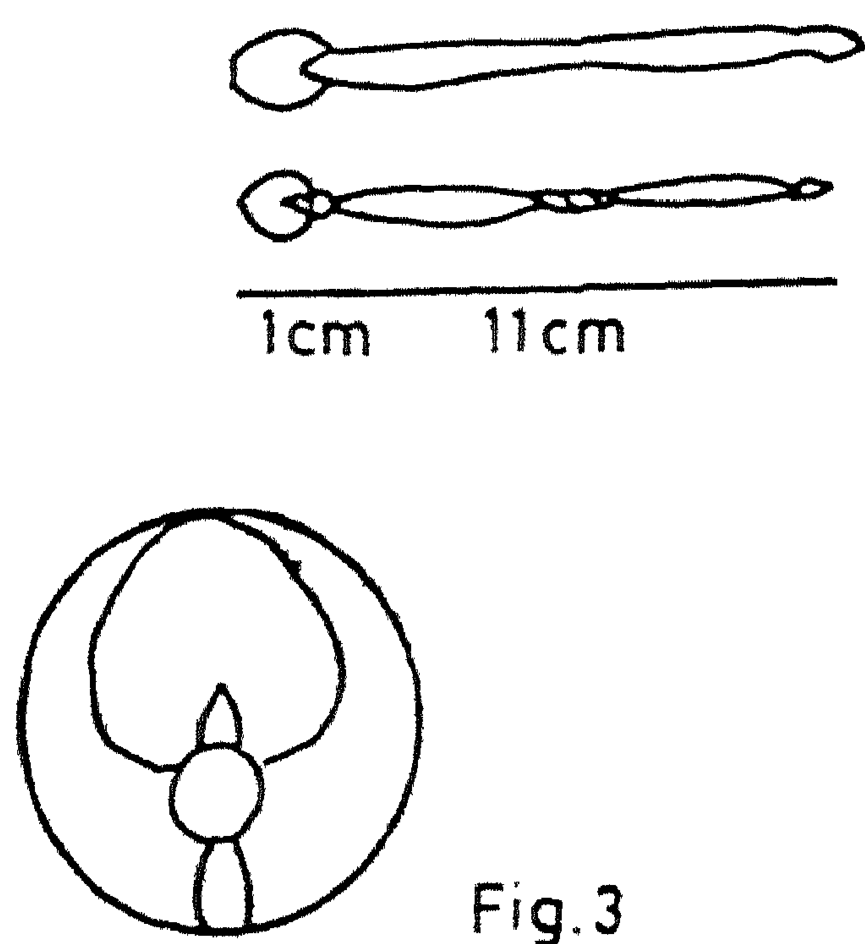
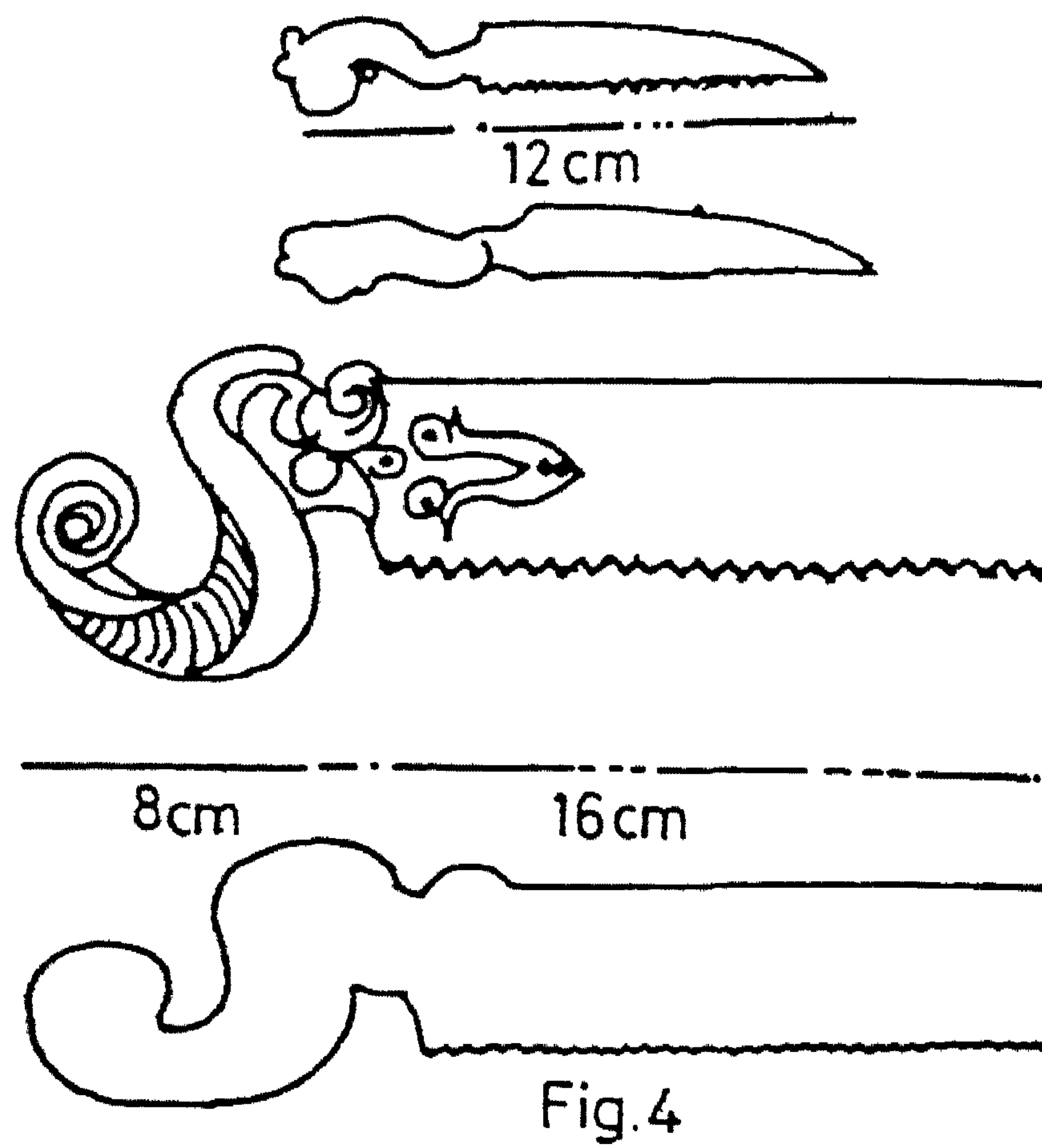


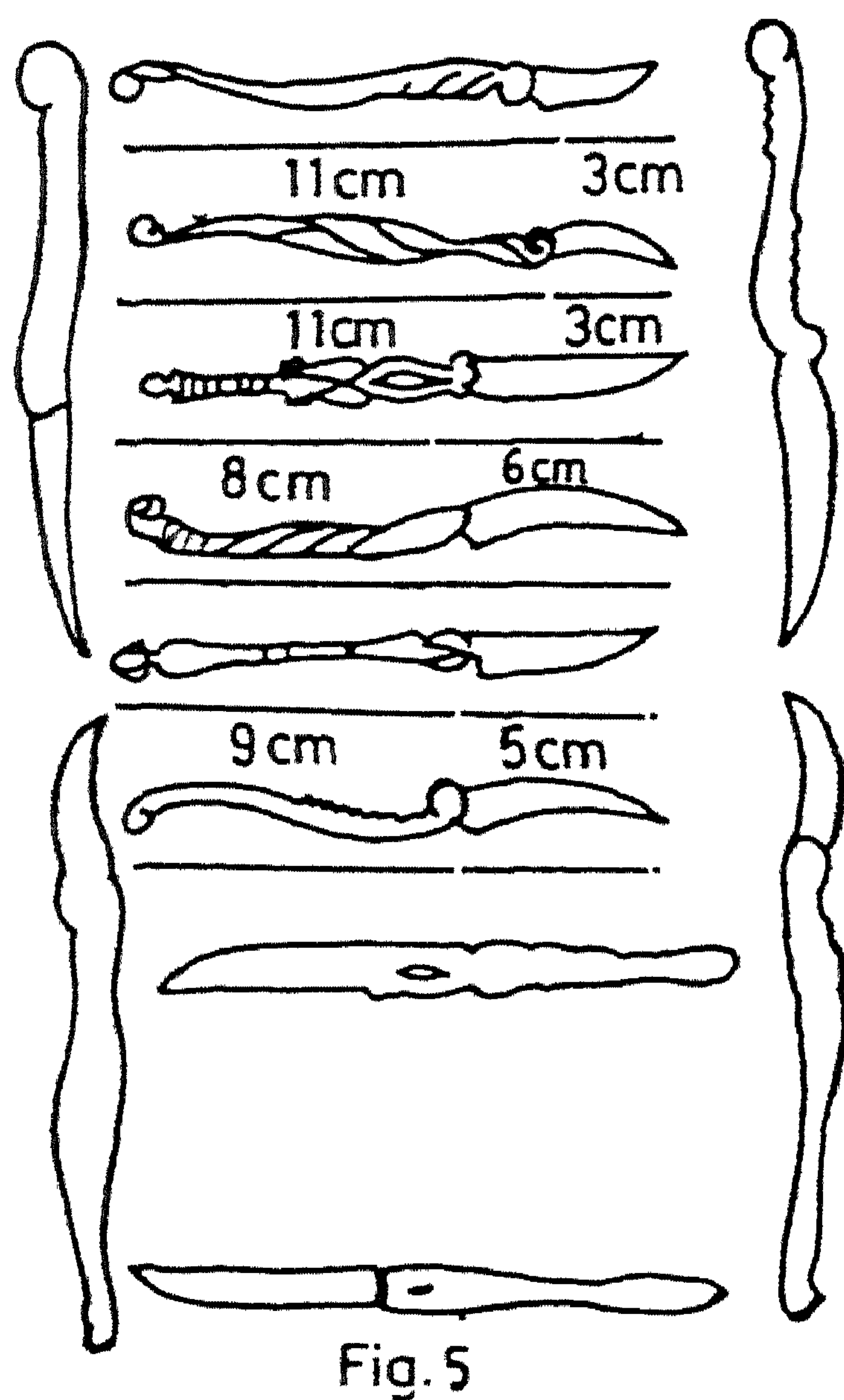
Fig.2. Some blunt instruments described by Suśruta

Hydrocele (Mūtraja Vṛddhi)

Technique - In a case of an enlargement of the scrotum due to the derangement of urine (Hydrocele), it should be first fomented and then a piece of cloth should be tightened round it. A puncture should be made in the bottom of the sac with trocar (*Vṛhimukha* instrument). Then a canula should be introduced into the







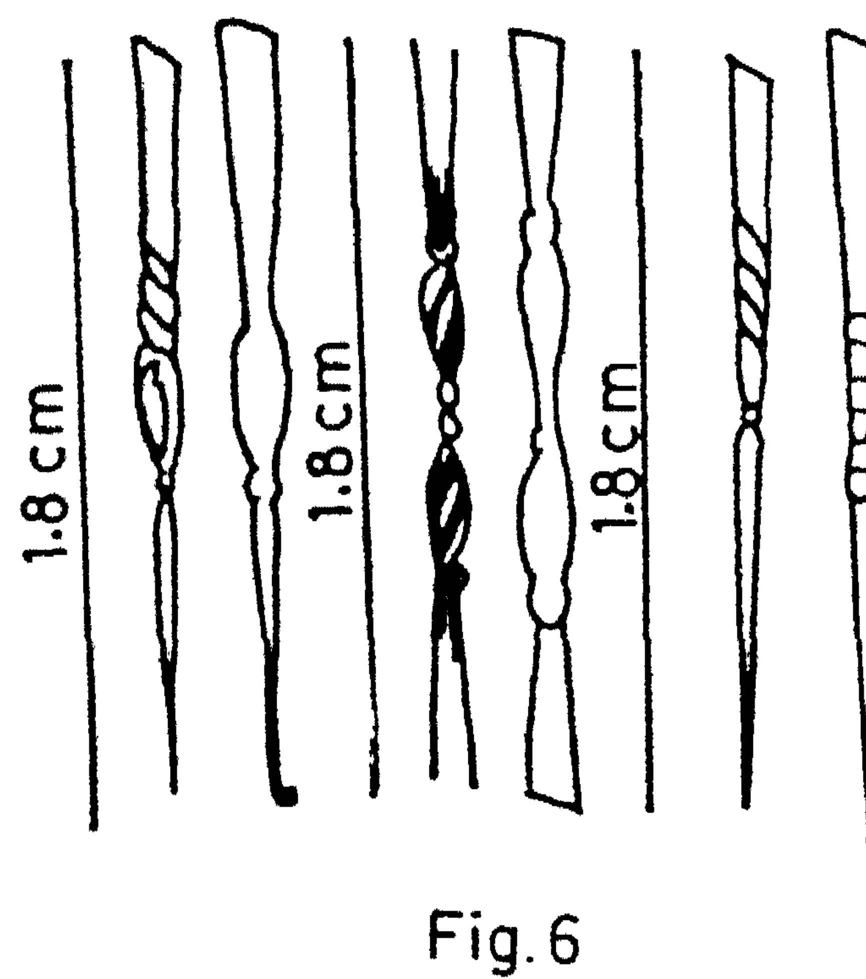


Fig.3. Maṇḍalāgra; Fig.4. Karapatṛa (saw); Fig.5. Vṛddhipatra (scalpel); Fig.6. Nakha Śastra (Nail Parer)

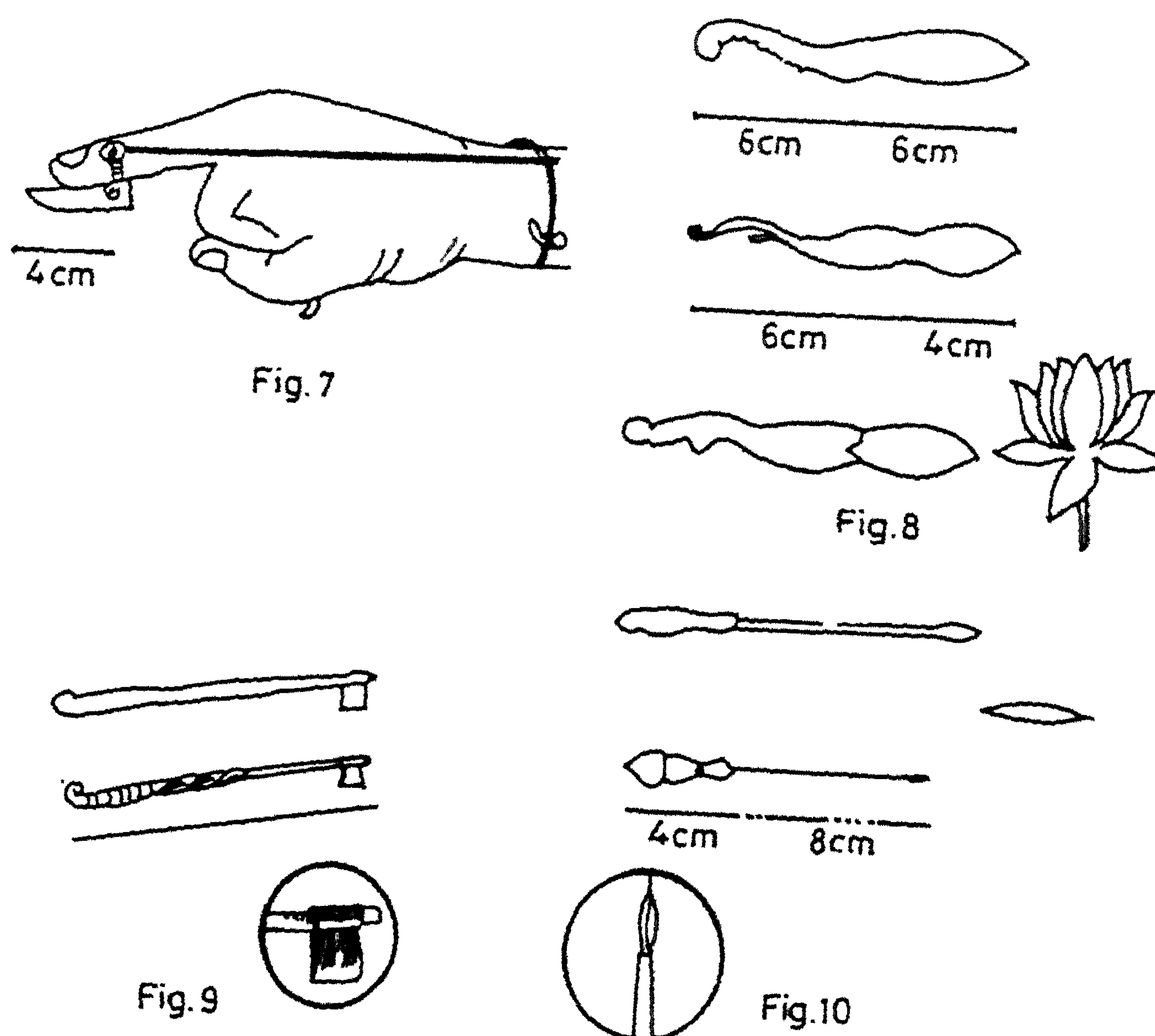


Fig.7. Mudrikā Śastra (Finger Knife); Fig.8. Utpal Patra Śastra; Fig.9. Kuthrikā (Lancet); Fig.10. Vṛhimukha Śastra (Trocar)

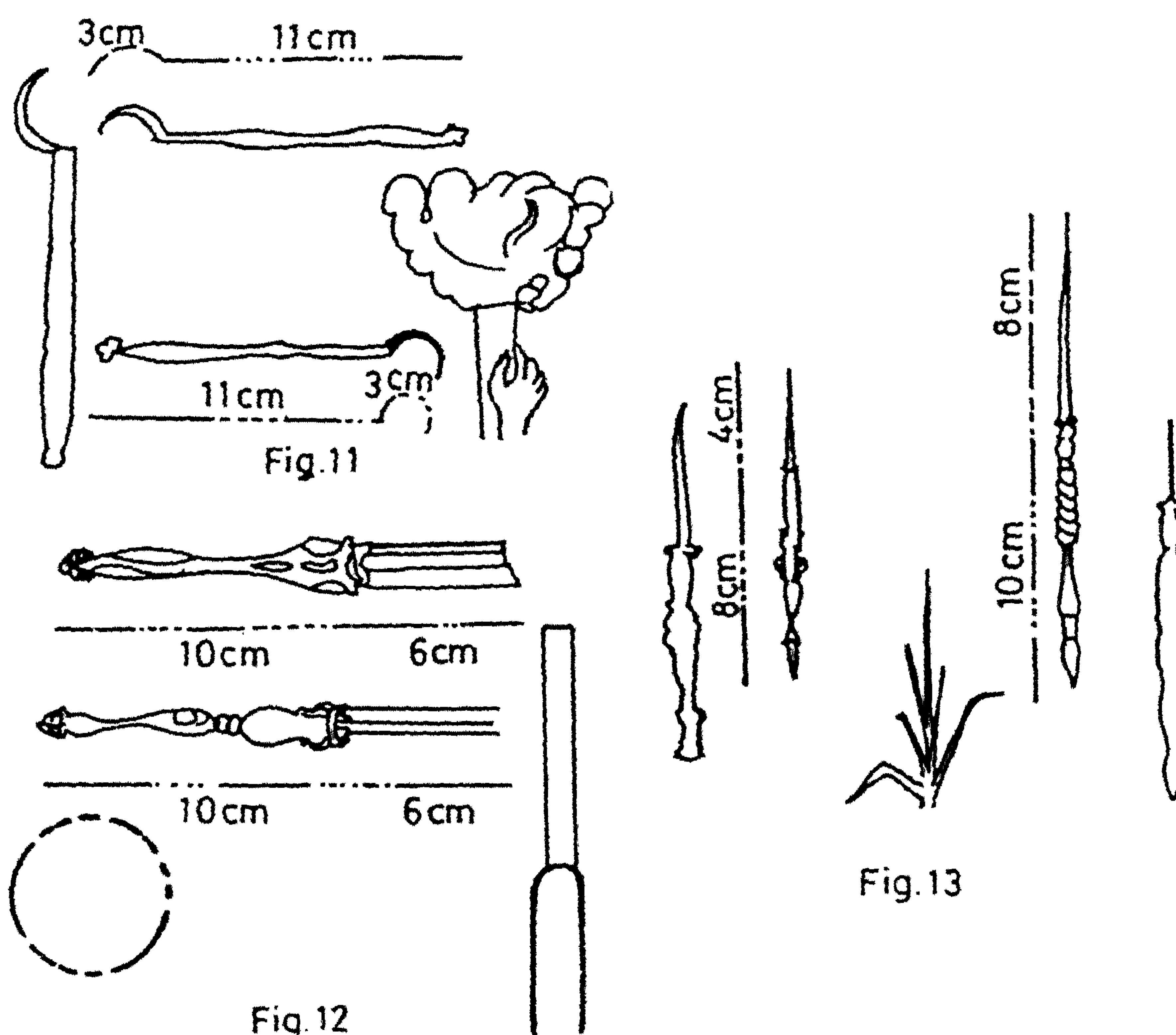


Fig.11. Lintarmukha (Curved Bistury); Fig.12. Trikurcaka (Brush); Fig.13. Kuśapatra (Pagets Knife)

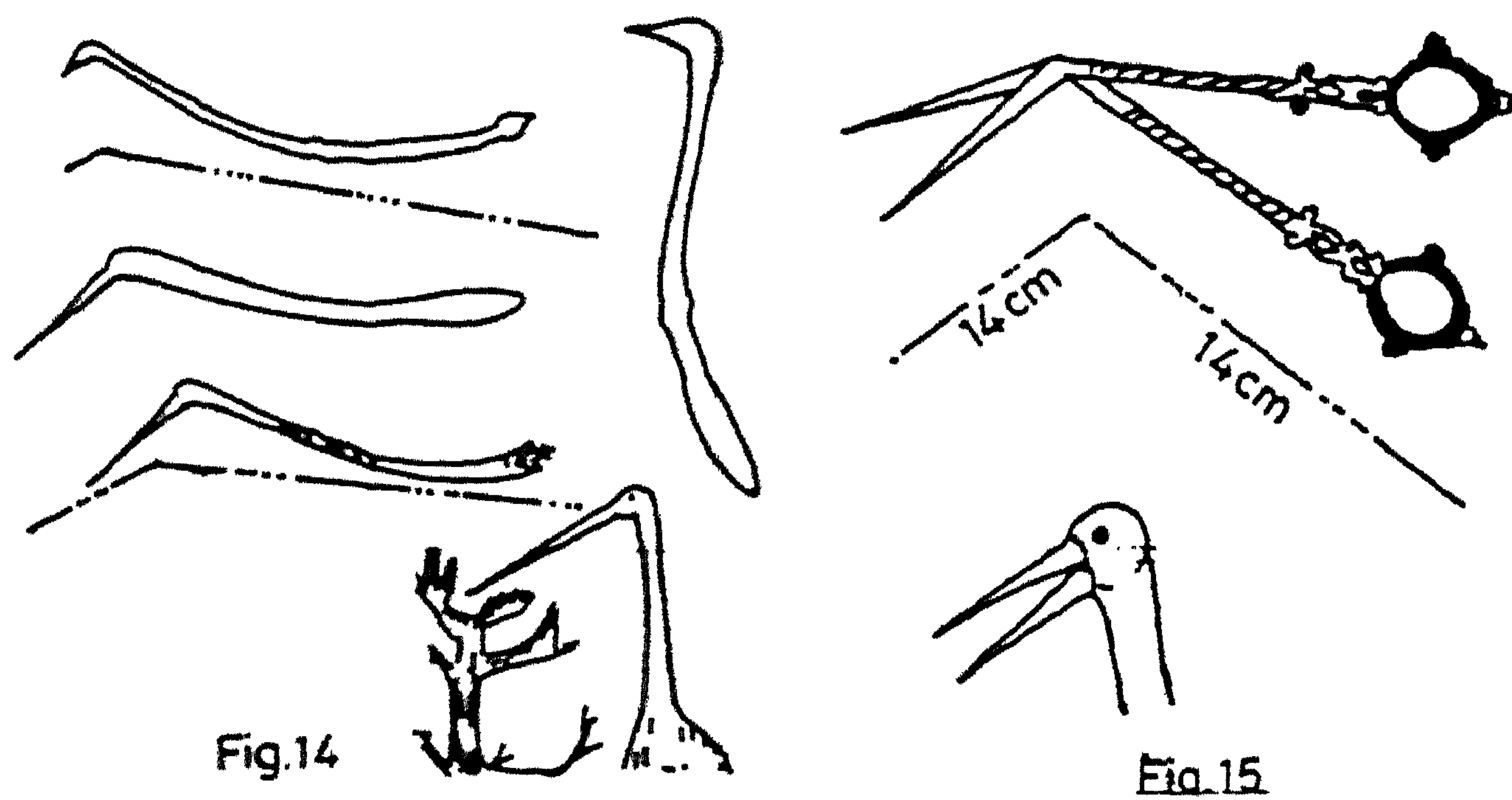


Fig.14. Atimukha; Fig.15. Sararimukha (Scissors)

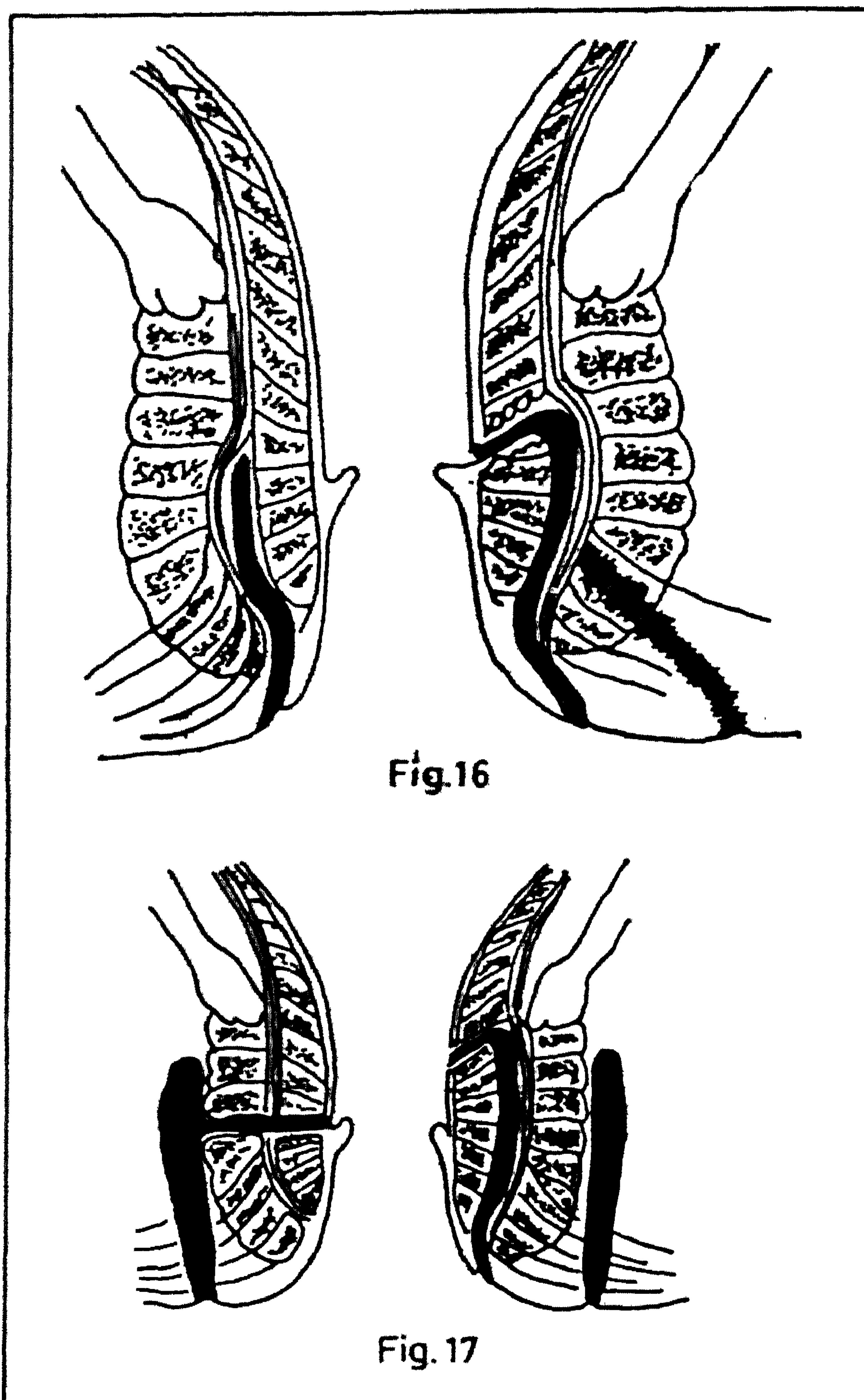


Fig.16. Diagramatic Section of the anal canal showing the position of the anal fistulae : Blind Low, External Fistula; Complete Low, Anal Fistula.; Fig.17. Complete Low Fistula (With high blind)

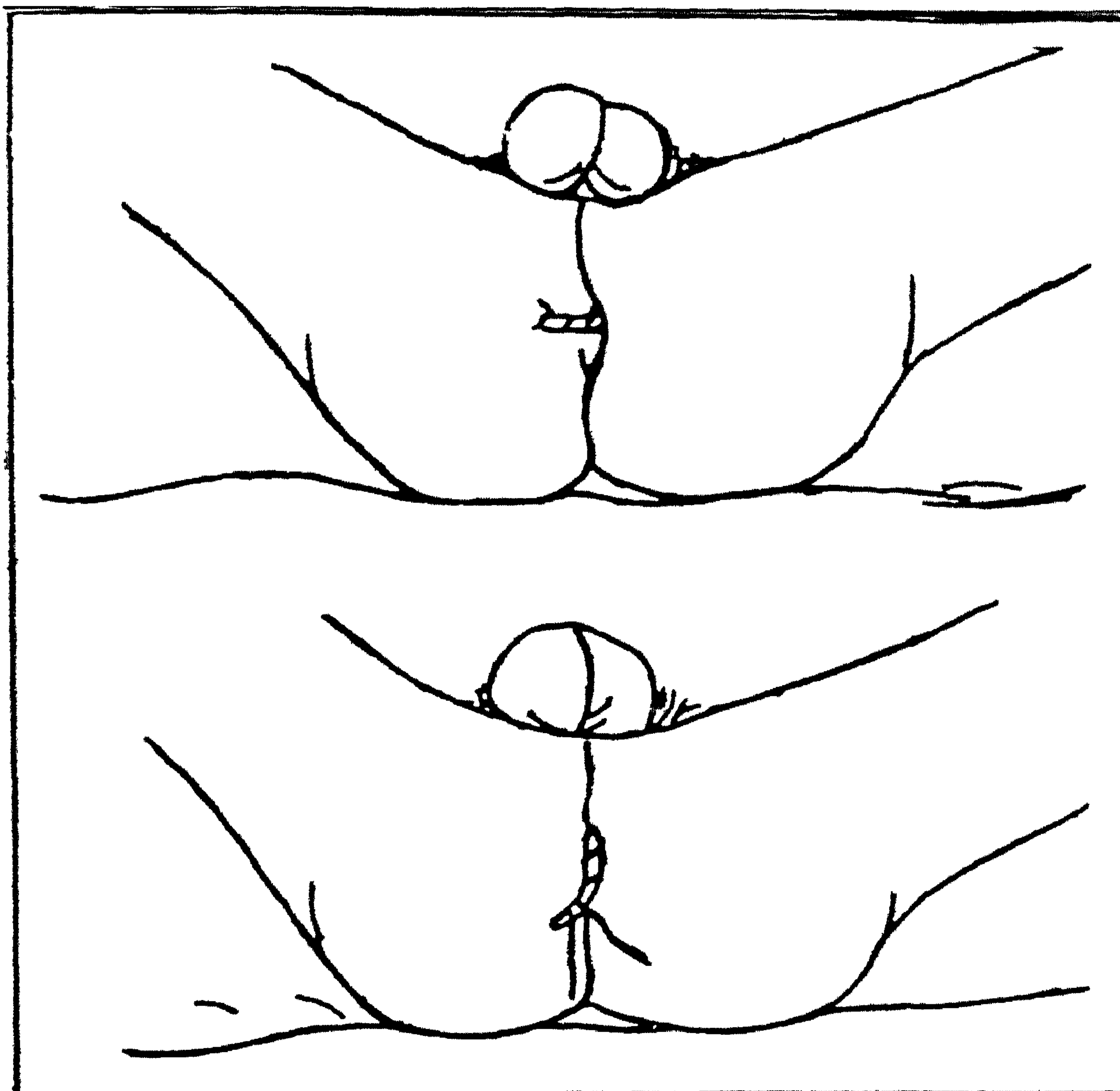


Fig.18. Kṣārasūtra (First day); Kṣārasūtra, (completed from external opening through internal opening)



Fig.19. The technique of Raktamokhana (Venesection)

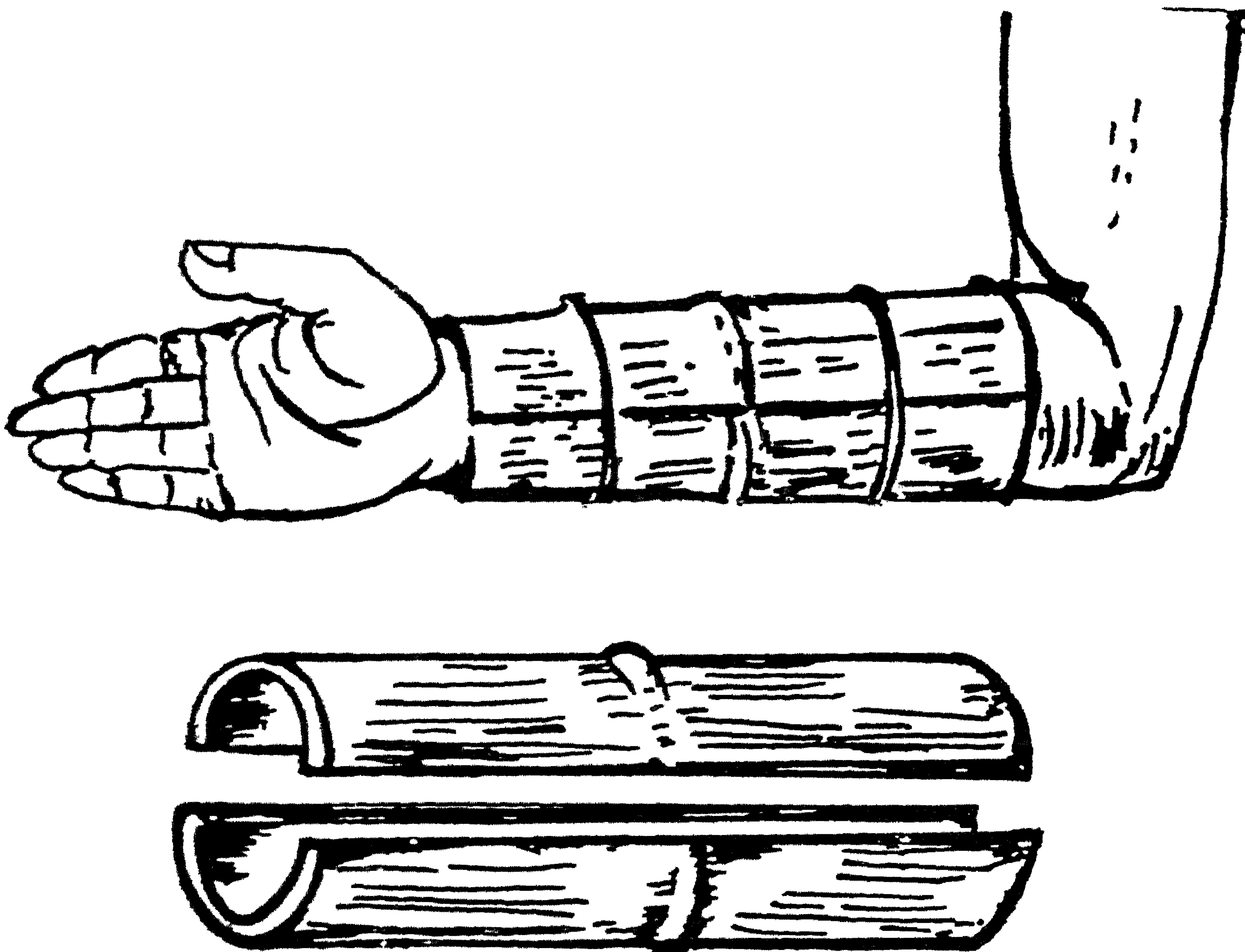


Fig.20. The Method of Spilintage of Fractured Bone by using bamboo.

puncture and the accumulated (morbid) fluid should be let out. The canula should then be taken off and the scrotum should be tied up with the stump bandage. When it has become clean healing procedures should be employed.

Inguinal Hernia (Antra-Vṛddhi)

Technique - The scrotal swelling due to the descent of the intestines should be avoided as irremediable. In a case of bubonocele the procedures indicated for pacifying vitiation of *Vāta* are beneficial. If the swelling is in the inguinal region fire cautery should be applied with a semilunar rod to obstruct the path. The complete hernias descending to the scrotum should be avoided. The skin of the thumb of the contralateral limb should be incised in the middle and cauterized with fire.

Plastic Surgery

Rhinoplasty

Manu mentioned ears and nose amongst the parts of the body on which punishments were to be executed. Cutting of the nose was the usual punishment for adultery. This gave ample opportunity to the ancient Indian surgeons for operation of otoplasty (repair of the ear lob) and rhinoplasty.

Technique - The technique and method of repairing the nose which has been chopped off, has been described in excellent scientific way. The portion of the nose to be covered should be first measured with a leaf. A piece of skin flap of required size should then be dissected from the cheek or from the forehead and turned back to cover the nose. The part of the nose to be prepared well by making it raw and the surgeons should join the two parts quickly but evenly and calmly and keep the skin properly elevated by inserting two tubes inside the nostrils, so that the new nose may look comely. The flap of the skin taken from the cheek or forehead is being kept intact for having proper blood circulation in the repaired area.

Suśruta has described these details in the most scientific way by quoting the verses in his treatise of *Suśruta Saṃhitā*, Sūtrasthānam, Chapter XVI.

Similarly, the Otoplasty as well as the repair of hare lip has been mentioned by Suśruta, the father of Indian Surgery in 6th Century B.C. (Fig. 21)



Fig.21. The technique of removal of skin flap for doing the Rhinoplasty

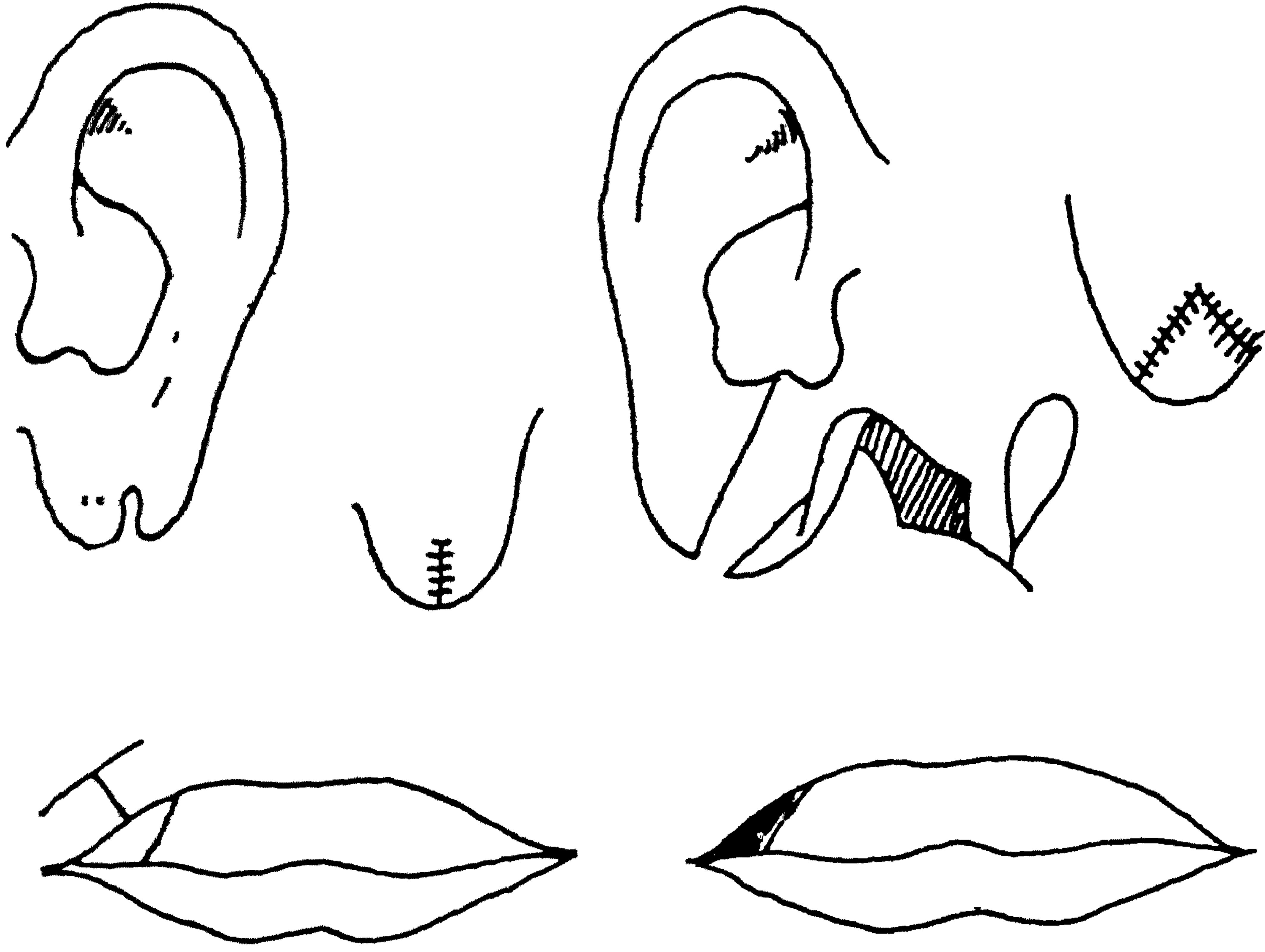


Fig.22. Suśruta's method of Plastic Surgery : Nemisandhanaka, Gamdakarṇa, Ear-Plasty and Lip- Plasty

It is well documented historical fact that the impetus to modern plastic surgery was provided by the reporting of Rhinoplasty through a forehead flap conducted by itinerant Indian Surgeons in 'Gentle men's Magazine' of London in 1794. Simplicity and success of the procedure was proved by Carpue in 1814 with minor modifications is still one of the standard methods of Rhinoplasty and is known as the Indian method of Rhinoplasty.

In fact, Suśruta has dealt with all aspects of plastic surgery while describing the repair of ear lobules.

Note

1 *Śiravyadhaścikitsārdhaṃ śalyatantre prakirtitaḥ*

(Suśruta)

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Medical Techniques

R.H.SINGH

Ayurveda, the ancient Indian Science of Life has its roots in antiquity. The early records about the medical techniques are seen in the Vedas, especially the *Atharvaveda*. But, most of these descriptions are in the form of terse aphorisms randomly scattered throughout the compendiums. In later days during ancient classical period the medical knowledge took a new organised shape and several schools of thought developed. Medical disciplines were developed from the 'Ātreya' school of thought, which had been contributed by the chief disciples of Atreya, by compiling classics individually. Among these the *Agniveśa tantra* popularly known as *Caraka Saṃhitā* stands as the finest document of the creative period of ancient Indian Medicine with regard to the extent of its contents and to the state of its preservation. *Suśruta Saṃhitā* and *Vāgbhaṭa Saṃhitā* both have contributed much to the conceptual and therapeutic aspects of ancient medicine. In the course of development of the art and science of medicine in ancient India a number of medical techniques were evolved which reflect on the technical skill in this field.

These medical techniques can be categorised into three groups as mentioned below:

1. Diagnostic Techniques
2. Prognostic Techniques
3. Therapeutic Techniques

Diagnostic Techniques

Diagnostic skill was the greatest achievement of ancient Indian Medicine. Caraka lays great emphasis on an early and correct diagnosis as the basis of any rational treatment. He devotes two complete *Sthānas*, the *Nidāna* and *Vimāna* in his 'Saṃhitā' to an exhaustive discussion of the subjects of different diagnostic techniques. Chapter 8 of the *Vimāna Sthāna* is perhaps the most comprehensive and complete discussion of the subject of diagnosis we possess in any ancient medical literature. The physicians conversant with this science, reflecting in all

manner of ways, upon everything as far as possible, should then come to a conclusion about the diagnosis of the disease before him and the treatment that should be followed. The physician who fails to understand the constitution of the patient with knowledge and perceptual vision can never treat diseases (*CS.VI.* 4.13-15).

The methods of approaching the patient to diagnose the ailment can be of two types.

1.1. Examination of the patient

1.2. Examination of the disease

Examination of the patient (CS. VI. 7.94-122)

Great emphasis was laid on the examination of a patient. This essentially involves the study of personality, strength and vitality of the patient. Caraka describes the following techniques for this purpose.

(1) *Prakṛti* (Constitution), (2) *Vikṛti* (Morbidity), (3) *Sāra* (Excellence of *Dhātus* or tissue elements), (4) *Saṃhanana* (Compactness of organs),(5) *Pramāna* (Measurement of the parts of the body) (6) *Sātmya* (Homologation),(7) *Sattva* (Psychic condition),(8) *Āhāra Śakti* (Power of Intake and Digestion of Food), (9) *Vyāyāma Śakti* (Power of Performing Exercise), (10) *Vayaḥ* (Age).

1. *Prakṛti*: Total constitution of the foetus is genetically determined by (1) Sperm and Ovum, (2) Seasons and Conditions of the Uterus, (3) Food and regimen of the mother and (4) Nature of the *Mahābhūtas* comprising the foetus. The foetus gets characterised with one or more of the *dosas* which are dominantly associated with the above mentioned factors when they initially unite in the form of foetus.

Prakṛtis are of seven types, three individual doṣic constitutions and three dual with combination of two *doṣas* and one with all *doṣas* in equal proportions. A detailed description of the qualities of individual constitutions is available in all major ancient classics of Indian Medicine. The *Doṣa Prakṛti* of an individual presents as the sum total of his physique, physiology and psychology and hence the Acāryas describe a comprehensive typology of human variation for determination of which an equally comprehensive technology is visualised.

2. *Vikṛti (Morbidity):* Morbid manifestations are to be examined with reference to the specific causative factors *doṣas* and *dhātus* involved in the pathogenesis, *prakṛti* or constitution of the individual, habitat, season and strength and also the symptoms of the disease.

Without determining the nature and strength of the causative factors etc it is not possible to know the nature of the disease. Moreover, morbidity helps in the assessment of the susceptibility and endurance pattern of an individual.

3. *Sāra:* Patients are to be examined with reference to *sāra* or the excellence of their *dhātus* and body tissues with a view to determining the specific measure of strength. They are classified into qualitative categories depending upon the *sāra* or excellence of their *dhātus*:

(1) *Tvak* (Skin, contextual meaning *Rasa Dhātu*), (2) *Rakta* (Blood), (3) *Māṃsa* (Muscle tissue), (4) *Medas* (Adipose tissue), (5) *Asthi* (Bone tissue), (6) *Majjā* (Marrow), (7) *Śukra* (Semen), (8) *Sattva* (Mental faculties).

The detailed description of the qualities of above types are mentioned in *Caraka Saṃhitā* with brief mention of the technique of determination of the *Sāra*.

4. *Saṃhanana*: A compact body is characterized by the symmetrical and well divided bones, well knit joints and well bound muscles and blood. An individual having a compact body is very strong, otherwise he is weak. When the body is moderately compact, the individual is possessed of moderate strength.

5. *Pramāṇa*: A patient is also to be examined with reference to *pramāṇa* or the measurement of his bodily parts. This is determined by measuring the height, length and breadth of different parts by taking finger breadth of the individual as the unit of measurement. This is called *Aṅgula Pramāṇa*.

The normal measurements of individual (all) body parts in *Aṅgula Pramāṇa* are described in all the three Saṃhitās. A body possessed of organs having proper measurement is endowed with longevity, strength *ojas*, happiness, power, wealth and virtues. If the measurements are not at par with standard norms the individual is considered weak and inferior.

6. *Sātmya*: Stands for such factors as are wholesome to the individual even if used continuously. Individual for whom ghee, milk, oil and meat soup as well as the drugs and diets having all the six tastes are wholesome, are endowed with strength, the power of facing difficult situations and longevities. Those who are accustomed to ununctuous things and drugs and diets having only one particular taste, are mostly possessed of less strength, less power (or resistance) to face difficult situations, are of smaller life-span and of meagre accessories like drugs for the treatment of his diseases. If there are combinations of both these types of homologation, individuals are possessed of moderate strength. *Sātmyāsātmya* is determined in terms of *Rasa*, *Guṇa* etc.

7. *Sattva* is mind and it regulates the body functions to a great extent of its association with the *soul*. Depending upon its strength it is categorised to be of three types viz. 1) Superior, (2) Medium, (3) Inferior. *Sattva Parīkṣā* is essentially the *Manobala Parīkṣā* i.e. examination of mental stamina.

8. *Āhāra Śakti*: One's capacity for food can be examined from two angles viz. (1) power of engestion, (2) power of digestion. Both these strengths and life-span are determined by giving a particular diet and by watching its digestion.

9. *Vyāyāma Śakti*: The patient should be examined with reference to his capacity for exercise in the fixed exercise endurance. Strength of individuals is classified into three categories depending upon the ability to perform works/exercise, viz. (1) Pravara, (2) Madhyama, (3) Avara.

10. *Vayaḥ*: The age of the patient represents the state of his body depending upon the length of the time that has passed since birth with a view to ascertaining the life span of an individual, and the rate of ageing process. A schedule of symptoms are described in the *Indriya sthāna* of *Caraka Saṃhitā*.

Examination of the disease

The ancient classical methods of investigation of disease are described under the following headings (*CS. Ni.* 1.7-11)

1. *Nidāna*: *Nidāna* essentially refers to the aetiology of disease. One finds extensive description of a wide variety of causative factors, viz. biological, psychosocial and environmental. The basic technique of detection of aetiology is interrogation and observation.

2. *Pūrva Rūpa*: This refers to the prodromate of the disease. By analysing this, the intensity and character of the disease can be ascertained at the earliest. It is also helpful in the prognosis. This description of prodromal symptoms and signs are seen in the texts while describing the features of the individual diseases.

3. *Rūpa:* The knowledge of the manifested characteristic features of different diseases is very important for the diagnosis and to assess the intensity of the disease. These descriptions are also seen in all major classics either in the Nidāna Sthāna or in the context of Cikitsā.

4. *Upaśaya*: It is a technique of diagnosis by utilising therapeutic test usually applied in cases where the etiology and symptomatology of a disease do not give conclusive clue to the predominence of *doṣa*. This diagnostic therapy is used in the form of diet, drug and or any other remedial measure to find out the original nature of disease.

5. *Samprāpti*: It is the description, in detail of all the morbid processes that take place in different diseases or in different stages of the same disease. The accumulation of *doṣas*, their movements and the particular form which the disease takes, are included in *Samprāpti. Dosa, Duṣya,* and *Adhiṣṭhāna* are the main *Ghaṭakas* or components of the *Samprāpti* of a disease.

These five techniques are useful to ascertain the character and strength of a disease.

The Four Pramāṇas of Ayurveda

According to *Darśaṇas* i.e. the systems of Indian Philosophy, the means of obtaining true knowledge are mainly three, viz.

(1) *Pratyakṣa* (perception)

(2) *Anumāna* (Inference) and

(3) *Āptavacana* (revelation, oral evidence or valid testimony).

These three, known as *pramāṇa* provide within themselves for a thorough investigation of all the material and abstract aspects of the universe. Hence they have been accepted as the methods of examination by all ancient Hindu Sciences including Ayurveda.

Caraka Saṃhitā (*Su.* 11.17) enumerates the above three *Pramāṇas* and adds one more, the *Yukti* as the fourth. In fact it is included in *Anumāna* itself but it has been given an independent status in view of its importance in practical application.

Three other techniques of examination

1. *Darśana Parikṣā (Inspection)*: Under this technique the physician has to inspect the *Varṇa* (colour), *Chāyā* (lustre and complexion), *Saṃsthāna* (shape, quality, external appearance features), *Pramāṇa* (number and proportion), *Prakṛti-Vikāras* (the normal and abnormal appearance of the body) and *Anuktam* which ever else not mentioned here but comes within the perview of the eyes like *saṃkhyā* (number, counting) *ceṣṭāgati, spandana* (movements, pulsations, throbing etc.) (*CS Vi* 4.7).

2. *Sparśana Parikṣā*: (Palpation) (*CS. In*. 3.3.): It is the hands of the physician that are essential for this examination. Through this technique physican can get the knowledge regarding '*Gunas*' like *Śīta, Uṣṇa, Mṛdu, Kaṭhina* etc. (qualities such as heat, cold, soft, hard and many other *spandanas* or pulsations); *sat* and *asat bhāvas*. etc (*Ca. Indriya* 3/4).

3. *Praśna parikṣā*: This is the technique of obtaining knowledge regarding the etiology and symptomatology of a disease by interrogation. This is an important technique which is ultimately helpful in the diagnosis and prognosis of a disease.

As a matter of fact *Praśna* or interrogation is the basic technique of all other clinical investigations. When the patient is in unconscious state, the well wishers and attendants of the patient (*Āptas*) are to be interrogated. This gives the first hand knowledge about the disease.

Nāḍī Parikṣā:Examination of pulse is another important diagnostic technique. The description about the *Nāḍī Parikṣā* is not available in the major ancient classics of Ayurveda. However, this technique appears to have been introduced during the medieval period by Sāraṅgdhara in the context of *Aṣṭavidha Parikṣā* i.e. eightfold clinical examination namely *Nāḍī* (Pulse), *Mūtra* (urine examination), *Mala* (stool examination), *Jihva* (tongue), *Tvak* (skin), *Dṛṣṭi* (eyes), *Śabda* (speech), *Ākṛti* (appearance) are described in details in *Yoga Ratnākara*.

The *Nāḍī* (pulse) is examined at the root of the hand i.e. at the wrist in a relaxed state. A pulse of very high rate with low pitch and volume gives the feeling of a serpentine movement which is characteristic of *Vātika Nāḍī*. A moderately rapid pulse with high pitch gives the feeling of a movement simulating jumping movement of a frog which is characteristic of *Paittika Nāḍī*. A pulse which is relatively slow in rate but high in volume gives the feeling of the movement of a swan which is characteristic of *Kaphaja Nāḍī* (*Sāraṅg.S*. 3. 1-8)

Mūtra Parikṣā: Urine examination has been an important technique for clinical diagnosis. Besides the physical examination in terms of colour, consistency, turbidity, taste etc the technique of *Taila Bindu Parikṣā* (oil drop test) is described in later texts. In this technique a drop of oil is left on the surface of the patient's urine and the movements of the oil drop in different directions and its rate of spread and change in colour etc are interpreted in terms of a number of chemical and physical properties of urine such as ph, specific gravity, surface tension etc. and also in terms of *Pañca Mahābhuta* and *Tridoṣa* (*YR*. 1, *Bās*. 3).

Mala Parikṣā: Examination of faeces is described as an important technique for diagnosis of a disease and disease state. Besides routine physical characteristics of stool such as colour, consistency appearance etc, an important consideration is the

Sama-Nirāma Parikṣā (*M.Ni.* 3, *Ma.K*, vs 12-13). For this a known amount of the faecal matter is dropped in water and if it floats on the surface of water it is inferred that the *Mala* is in *Nirāma Avastha*. If it dips in water it is considered *Sama*. The degree of *Amavastha* can be measured quantitatively by measuring the degree of dipping of the stool in depth of water. It is a very useful technique which can be interpreted in a variety of ways giving significant information on digestive and metabolic state of a patient.

Prognostic Techniques

The art of prognosis was highly developed in ancient Indian Medicine. The origin of the art of prognosis has to be traced to the inherent desire of the physician to know with some certainty what would be the outcome of his treatment and the course which the disease he was treating would take. In pre-vedic times when the cause of disease was attributed to external agencies the modest physician looked to these agencies for some guidance as to the outcome of the disease. But as magic and witchcraft were replaced by empiricism and reason, prognosis assumed a different aspect. It was common experience that some patients died inspite of adequate treatment. As Caraka remarks, there are patients that meet with death not withstanding the application of treatment in its entirety. Not all patients by obtaining treatment obtain recovery. The reason is that not all diseases are capable of cure. The great problem therefore was to discover what were the factors that influenced the course of treatment for good or ill and how to ascertain them before hand i.e. before the treatment was commenced 'Men die' says Suśruta from their action of former life, from improper treatment, and from the uncertainty of human life. When life is about to depart, spirits ghosts and demons approach the dying and from their desire to kill, prevent the action of medicine hence no treatment is effective with persons whose lives are at an end (*SS. Sū* 31. 31).

That is why such great emphasis was laid on the ascertainment of the period of life expectancy. The physician on approaching a patient should first test his longevity and see if he has any vitality in him says Susruta. So also Caraka at the commencement of *Indriya-Sthāna* mentions several items that should be examined and attended to by the physician desirous of ascertaining what the patient's life expectancy is.

Caraka in *Indriya Sthāna* deals with the subject of prognosis on the same lines which he employed in the study of diseases. To find out what are the indications for ascertaining the life expectancy, he proposes to conduct this examination by means of direct perception, inference and the instructions of the wise, the same three methods he employed in connection with the study of diseases, viz., *Pratyakṣa*, *Anumāna* and *Āptopadeśa*.

These prognostic symptoms and signs can be classified into two categories.

1. ***Puruṣa Samsraya***: Those fatal features which are actually found in the body of the patient.

2. ***Puruṣa Anasraya***: Those which are outside the body of the person. These are the features seen in the family members of the patient and surroundings. Of these

two, it is the former which is given more importance and not the latter. Further, the former is again sub-divided into three groups.

1.A. *Lakṣaṇa Nimitta*: There are certain feature present since the birth of the person such as *hasta rekhā* (lines in the palms), *padarekhā* (lines of the soles), auspicious and unauspicious features of different parts of the body. This branch of knowledge known as Sāmudrika Śāstra (physignomy) has its own separate literature. It's detailed description is not seen in ancient Ayurvedic classics.

1.B. *Lakṣya Nimitta*: These are fatal features appearing in the course of various diseases affecting human beings. The elaborate descriptions of these features are seen in the classics which is very relevant to medical science.

1.C. *Nimittānurūpa*: These are fatal features which invariably appear in every person prior to his death without any reason except death. There are definite features heralding death and so are the real fatal signs in the real sense of the term.

Observing these, death can be predicted if the physician is well experienced in recognising them. Ayurvedic classics have also described these features to some extent.

The Ancient Indian prognostic skill displays, on one side wonderful perception and power of observation, while on the other hand it literally abounds in evidence of primitive superstition. In this connection may be indicated their belief in dreams and the ominous influence of purely fortuitous occurrences previous to visiting the patient. Great stress was laid on the occurrences of celestial phenomena, Susruta says, "the physician should not be called in the following lunar asterism *Kṛttikā*, *Ārdrā*, *Āślesā* etc. and the following days of the moon viz., the fourth, sixth and ninth and the day of new moon". In addition to celestial phenomena, all events of note, encounters etc. assume the role of portents, affording an insight into the future fate. Particular attention was paid to the dreams of the patient. Both Caraka and Suśruta describe such dreams and their importance in detail. Indian Medical texts give lists of omens that indicate prognosis. In these both good and bad prognostic omens are narrated in all the three major classics.

Therapeutic Techniques

If we see the chronological evolution of therapeutic skills in ancient India, the major developments took place in the classical period. In the pre-vedic and vedic period the cause of disease was attributed to evil forces and supernatural beings, hence the therapeutic measures were also directed to pacify those powers. In later years of classical era the intellectual development of man made roads to develop newer diagnostic sills to ascertain the cause and nature of disease. The establishment of *Tridoṣa theory* was an impetus for the comprehensive development of systematic medicine in ancient India. The diseases were thought to be due to derangement of *Śāririka* and *Mānasika doṣas*. The therapeutic methods were also rationalised and directed to bring normalcy in the initiated *doṣas*. Three dimensional approach towards human entity, considering soul (*Ātmā*), mind (*Mana*) and body (*Śarīra*) as the three basic components of living entity was another development by which ancient Indian Medicine reached its zenith by evolving holistic approach towards the patient.

All the three major classics in general and *Caraka Saṃhitā* in particular contributed much to the development of rationalised therapeutic skill.

Several classifications regarding therapeutic measure are seen in different contexts of the three major classics. The widely accepted classifications are quoted with brief descriptions. For the detailed study of these techniques the original classics may be referred.

Three major branches of therapeutics (*CS.Sū.*11. 54-55) are recognised in the ancient Indian system of medicine.

1. Daiva Vyapāsraya Cikitsā
2. Yukti Vyapāsraya Cikitsā
3. Sattvāvajaya Cikitsā

1. Daiva Vyapāsraya Cikitsā: This is one of the three major methods of treatment that goes back to a hoary past, and finds mention in *Ṛgveda* as well as in the *Atharvaveda*. This method relies on divine intervention (*Daiva*) (*CS. Sū.*11.54). In life, the divine or unseen element (*Daiva*) comprehends past actions and their depositions *Devaḥ* (Gods) and human effort (*Puruṣakāra*) are together involved in health as well as in disease. When the former is weak, human effort can surely counteract it, in any case, human effort is able to minimise the severity of diseases caused by '*Daiva*' factors (*CS. Vi* 3. 33).

Diseases such as *Unmāda* (insanity), *Apasmāra (epilepsy) Kuṣṭha* (certain skin diseases) and *Bāla graha* (childhood maladies) all of which cannot be ascribed to physical or mental causes are included in this category.

The techniques of therapy include the employment of incantations (*Mantra*), precious stones and sacred gems (*Maṇi*), auspicious rituals (*Mangala*), oblations (*Bali*), gifts (*Upahāra*), sacrifices (*Homa*), penances (*prāyaścitta*), fast (*Upavāsa*), benediction (*svastayana*), bowing before elders and divine beings (*Praṇipāta*) and visits to sacred spots (*Gamana*) etc. all of which are intended to counteract the force of unfavourable past action (*Daiva*) and to secure divine influence in order to eliminate the diseases.

Most of these techniques are inherited from *Atharvaveda* while Ayurveda in theory considers the curative value of these practices. It attaches importance to rational methods like proper medicine, beneficial diet and favourable habits.

2. Yuktivyapāsraya: Treatment of diseases by the employment of reason viz. clinical examination (*Parikṣā*), diagnosis (*Nidāna*) and employment of drugs, prescriptions of diet etc. in terms of the basic doctrines of Ayurveda viz. *Pañca Mahābhuta, Tridoṣa* etc. is called *Yukti Vyapāsraya Cikitsā*. It broadly includes three varieties of treatment, viz. -

2.A. *Antaḥ Parimārjana* (Internal Cleansing)

2.B. *Bahiḥ Parimārjana* (External Cleansing)

2.C. *Śastra Praṇidhāna* (Surgical Intervention)

2.A. Antaḥ Parimārjana: diseases caused by improper diet, etc are eradicated by medicines meant for internal cleaning. This method consists of two main procedures (i) *Saṃśodhana* - general cleansing of the entire physical constitution

through *pañca karma* therapy utilising the techniques of *Vamana*, *Virecana*, *Vasti*, *Śirovirecana* and *Raktamokṣaṇa*. (ii) *Saṃśamana* - general palliation of the constitution through drugs, diet, and exercise etc.

2.B. Bahiḥ Parimārjana: The cleansing therapy which has its curative effect by external contact with the body such as massage, fomentation, unction, affusion and kneading etc.

2.C. Śastra Praṇidhāna: The surgical intervention involves the performance of eight surgical techniques like incision, excision, scarification, puncturing, probing, extraction, evacuation and suturing with the help of sharp instruments and blunt instruments. It also includes potential and actual cautery (*Kṣāra* and *Agni*), venesection and blood letting by leeches. This branch was developed from the Dhanvantari School of thought.

The *Suśruta Saṃhitā* mainly deals with this branch, in addition to the other therapeutic skills. Surgical treatment was reserved for those diseases which do not come entirely under the category of medical treatment.

3. Sattvāvajaya Cikitsā: The expression '*Sattva*' has many meanings but in this context it means 'mind' (*CS. Sū* 1.46). Subjugation of mind has been prescribed as a special therapeutic technique to deal with psychic and psycho-somatic diseases. This has the import of psychotherapy and counselling for it is reduction of mind to restrain itself from unwholesome preoccupation. *Caraka* argues that most of our troubles are due to folly or errors of judgement (*Prajnāparādha*) and to avoid or eliminate the troubles one must live correctly (*Sadvṛtta*). Correct living, according to Ayurveda, does not involve supernatural sanction or vedic authorities. It is a wholesome integrated living which adequately fulfills the three fundamental motivations i.e. urge for self preservation (*Pranesana*), the desire for material provisions which make life comfortable (*Dhāṇeṣaṇa*) and a longing for better state of existence, here and hereafter (*Paralokaiṣaṇā*).Ethics is thus judiciously subordinated to pragmatic considerations.

The development of this dimension in the classical era fulfilled the lacuna of therapeutic skill and made the approach of Indian system of medicine towards the health demands of the society as a comprehensive and holistic one (*CS. Su.* 1.46 *CS. Śā.* 1.108).

In principle, the Ayurvedic approach to the treatment of a disease consists of two major procedures (*CS. Vi*, 7.30).

1. Saṃśodhana Cikitsā
2. Saṃśamana Cikitsā

Saṃśodhana Cikitsā is the radical treatment of a disease and is supposed to eradicate or eliminate the vitiated *doṣas* thus completely preventing and curing the disease. *Saṃśamana Cikitsā* is the conservative treatment which consists of conservative measures like *Laṅghana* (fasting) *pacana* (digestion) etc. by administration of appropriate drugs designed for subsiding or alleviating the vitiated *doṣas* thus preventing temporarily or subsiding a disease.

Pañca Karma (literal meaning, five-fold therapeutic action)is a collective expression for the cleaning of the physical constitution (*Saṃśodhana Karma*).

Karma in this context signifies specific action directed towards therapy, and therapy here is directed towards the elimination of the vitiated *doṣas* for the purpose of cleansing the constitution, and therefore all the therapeutic actions listed under this head are properly cleansing devices (*Śodhana*). They are also eliminative processes and are therefore generally called the *Laṅghana* treatment. The exception is the '*Anuvāsana Vasti*' which is *Bṛmhaṇa* in nature.

These treatments are resorted to when the normal pacification treatment fails to correct the disturbed *doṣas*. Their main purpose is to eliminate the vitiated *doṣas* from the body, and thus cure the diseases. While they are curative in their import, they may also be employed as preventive and promotive measures, for they are also prophyllastic.

Normal health is resultant of these treatments, and a resistance against the factors that are likely to upset the balance of the *doṣas* is built up; longevity is a side-benefit. Body metabolism is rendered efficient, and digestion normalized, sense-functions become alert, body strength is enhanced, and mind becomes clear and sharp. The degenerative processes in the body are effectively stalled or slowed down (*CS. Sū.* 10.17-19).

This line of treatment has five major procedures viz.,

(1) *Vamana* (Emesis),

(2) *Virecana* (Purgation),

(3) *Nirūha vasti* (Evacuation by Enema),

(4) *Anuvāsana Vasti* (Unctuous Enema),

(5) *Nasya* (Errhine Therapy or Nasal Insufflation).

This is also the order in which the treatment is carried out. But before emesis, it is advisable to administer to the patient two preoperative treatments, (*Pūrva Karma*) namely *Snehana* (Oleation) and *Svedana* (Sudation). [14]

There are five therapeutic operations according to the *Caraka Saṃhitā*; there is a slightly different list in the *Suśruta Saṃhitā*. The two '*Vastis*', *Anuvāsanavasti* (called *Snehavasti* in the *Suśruta Saṃhitā*) and *Niruhavasti* or use of decoctions as enemata are in the *Suśruta Saṃhitā* under one head, and blood letting (*Rakta Mokṣana*) has been enlisted as the fifth (*SS. Ci.* 36 17). This is based on the idea that blood is the fourth *doṣa* and that a large number of diseases are caused by its vitiation (*SS. Sū.* 21.3).

The two pre-operations (*Pūrva Karmas*) are helpful in loosening the vitiated *dosas* which are struck in the body tissues, releasing them for circulation and into the alimentary canal, so that they may be thrown out by the principal operation i.e. *Vamana*, *Virecana*, *Vasti* etc.

Snehana (Oleation): The preparations containing fat i.e. oils, ghee, animal fat and bone marrow are administered internally and externally through food, massage, inhalation, enema and so on and render the body soft, disintegrate the accumulated *doṣas* and clear the accumulated and obstructing waste products from the channels of circulation (*CS. Sū.* 8).

Svedana (Sudation): After the oleation therapy, application of sudation is done. These may be unctuous, for example with ghee, oils, vapour bath, or dry with heated

sand, hot bricks, husks of cereals, sun-bath etc. Forms of sweating without the employment of heat (*Niragni*) that is by exercise, warm clothing, hunger, popultice bring out sweat which is an internal secreta of the body, and this liquifies or melts the *doṣas* held in the subtle channels of the body and also the waste products of metabolism (*CS. Sū.* 14; *CS. Si.* 1.7)

These two *snehana* and *svedana* help bring the chief of the *dosas*, *fatal*, under control, so that in the course of the principal operations (*śodhana*) the entirety of the vitiated *dosas* can be thrown out.

1. *Vamana (Emesis)*: This is the first of the *pañca karma* series and consists in causing vomiting of the vitiated *doṣas* especially *kapha* from the upper parts of the body, by means of suitable recipes which possess repulsive, nauseating, indigestible and tending to move upward qualities. When this is properly administered, the emesis occurs; first salivation then the medicines taken, followed by *kapha*, *pitta* and *vata* in that order (*SS. Ci.* 33.22; *CS. Si.* 1-15). Channels of circulation are cleared, sense functions become effective; lightness in body and heart and clarity of mind are ensured. The emetic treatment is especially indicated in diseases when the vitiation of *kapha* figures prominently.

2. *Virecana (Purgation)*: The administration of purgatives the drugs which are pleasant/palatable, easily digestable, and tending to move downward in order to eliminate the vitiated *doṣas* especially the *pitta* from the lower regions of the body as taken from the stomach to the large intestine and expelled through the anal passage. When properly carried out, the expelled contents will be in this order, viz. faeces, urine, '*pitta*', medicines taken and *kapha* (*SS. Ci.* 33.22). Clarity of mind, efficiency of sense organs, stability of the bodily constituents, vigour and good digestion are brought about by proper purgation (*SS. Ci.* 33.26). The treatment through purgatives is especially indicated in diseases where the vitiation of *pitta* along with initiative of *kapha* figures prominently.

3. *Anuvāsana Vasti*: Enemate with unctuous substance i.e. the administration of unctuous drugs (oil, ghee, animal fat) into the rectum through enema, inorder to eliminate the vitiation of *vāta*, which is the chief among the *dosas*. This is regarded as an extremely beneficient treatment, good for old and young alike, for the fat and the lean alike, it helps rejuvenation secure good health and prolongs life (*CC. Si.* 4.55; *SS. Ci.* 37-58)

A variety of this unctuous enemata is known as *Mātrā Vasti*, which is harmless and involves no restriction of diet behaviour, time of the day or season of the year. It is suitable even for daily use by those who are emaciated, debilitated and overworked.

4. *Nirūha Vasti*: Enemata with decoctions of drugs (*kvatha*), milk, juice is also meant to eliminate the vitiated *vata*. Many varieties of these *Vastis* are recognised, viz. *Utkleṣaṇa* which removes the vitiated *doṣa* from its location, '*doṣāhara*' which actually expels the *doṣa* from its location and *śamana* which cools, soothes or ameliorates the *doṣa* after the vitiation is removed from it, '*Lehana*' a mild variety of *Nirūhavasti*, *Bṛmhaṇa* - Nutritive in effect and '*Piccha*' emollient in irritation of the colon (*CS. Si.* 3; *SS. Ci.* 35.18).

5. *Nasya Karma*: Errhine therapy or nasal insufflation is described as a purgative to the head (*Śiro-virecana*). It consists in introduction into the nostrils, suitable medicines in liquid form (oils or *taila*) or powder form (*cūrṇa*) in order to throw out the vitiated *doṣas* from the parts of the body above the classic. The treatment is administered through the nose, because the nose is the gateway to the head. Three varieties of therapy are recognised purgative or eliminatory (*Recaka*) nourishing or cooling (*Tarpana*), and sedating or alleviating (*Śāmaka*) (*CS.Si.*9. 89-92).

All these five therapeutic operations are considered major and special precautions regarding diet and regimen are prescribed before and after these procedures. Some ancilliary therapeutic techniques are also described in the Ancient Indian Medical Classics while dealing with some special diseases.

Ancillary Therapeutic Techniques

Dhūmapāna (fumigation in the nose or mouth)

According to *Caraka* the medicines to be used are powdered and kneaded into a ball which is fixed to the end of a seed-stalk.

When the ball is dry, the stalk is pulled out, the tube thus formed is put in pipe of metal, wood or ivoy, it is then kindled and the other end of the seed is put into the nose or mouth. According to Suśruta, there are five kinds of *Dhuma* (*SS. Ci.* 40; *Aṣṭ Hṛ. Sū.* 21.10).

Kavalagraha and Gandūṣadhāraṇa: (Mouth rinsing and gargling): The techniques are prescribed particularly for the diseases of mouth and teeth. The fluid is to be retained in the mouth until tears come out of the eyes and drops begin to fall down from the nose, then a new portion of the fluid is to be taken (*SS. Ci.* 40).

Āścyotana: Instilling of drop for the aliments of eye is prescribed.

Pradeha: softening popultices.

Varti or Phalavarti: Suppositories for use in narrow orifices of the body (*Kāś. S. Si.* 6; *CS. Si.* 9.65-66) etc.

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Textile Technology

LOTIKA VARADARAJAN and KRISHNA AMIN PATEL

Introduction and Methodology

In the absence of substantial material remains of Indian textile technology[1] in the pre-Islamic period we have depended more on the vibrancy of craft tradition both in terms of techniques, processes, tools and implements as well as that of hereditary skills transmitted across generations. The task of identifying the constituents of a tradition which existed at a remote period of time in India, is, therefore facilitated by the existence of a wide data base of ethnological evidence which lends itself to selective usage. The criteria for selection can be rationally explained as material artifacts and a living craft tradition are both subject to an inner logic which shapes the nature of innovation accepted and the norms which guide selectivity in obsolescence. This topic will not be taken up here as it involves aspects of a wide ranging methodological enquiry beyond the scope of the present exercise. For the purposes of this article, development in the area of textile technology will be broken down into its components of fibre, natural dye and loom structure.

Fibre

Fibres used in India can be accommodated within the categories of bast, wool, silk and cotton. Animal skin and bark cloth [2], are, therefore, being excluded. Felt, *nāmdā* [3], being non woven, may be classified as a *fabric* rather than a *textile*, and has been eliminated from the purview of this survey.

Bast Fibres

The term bast fibre covers the category of strong ligneous fibres of which the most important are flax, hemp, jute and ramie, separated by the process of retting from certain parts of plant tissue. For the proper utilisation of such fibres the precise point at which further decomposition has to be arrested has to be accurately guaged. Fibres may be either woven into clothing or be diverted to the manufacture of cordage and meeting.

Linen, referred to as *Ksaumā* in early texts, is obtained from the plant *Linum usitatissimum*. The plant is called *Umā* in the *Caraka Saṃhitā* while Pāṇini uses the term *Kṣumā* and *atasi*. *Uma* and *Kṣumā* had the connotation of linen while *atasi* had that of linseed oil (Singh, M.N. pp.11-12). *Linum usitatissimum* was not indigenous to India and in antiquity it was cultivated in Egypt, Europe and Northern India. The attempt to popularise that plant for its flax fibre failed in this country, but as a source of linseed oil it was extensively cultivated (Singh, M.N. p.1)[4]. Flax fibres are long, lustrous, strong, and can stand up to high tension. They are smooth, hard faced, inelastic and resistant to abrasion. They are good heat conductors and readily absorb water.

On the loom, warp ends can be set closely together as they are marginally affected by rubbing of adjacent warps when there is a change in shed. Individual fibres of good quality flax can be so delicate as to be close to being invisible, and very fine gossamer thin fabrics can be woven from such fibre. When flax is grown for fibre the seeds are sewn close together so that the stems grow straight and there are a minimum number of branches (Baines, p.3; Carrol, p. 15).

The earliest references to *Kṣaumā* in the sense of linen garments occur in the *Maitrāyanīsaṃhitā* (3.6.7), and the *Taittirīyasaṃhitā* (6.1.1-3)[5]. Domestic production could not have been sufficient at all times to meet the demand and supplies must have been drawn from other sectors. Circa B.C. 600, the Phoenicians were distributing Egyptian linen in the Mediterranean region (Broudy, p.47). Since there is indication of the Phoenician network penetrating into Babylonia it would not unreasonable to surmise that Egyptian linen was vended in India through a distribution system linking Western India to Babylonia through the Persian seaways. When the Roman market impinged on the Erythraean Sea, Egyptian linen was exported to India through intermediaries in Roman trade in payment for spices (Frank, p. 282)[6]. The predominant demand appears to have been for fine quality linen and in the *Amarakośa*, *Kṣaumā* is regarded as synonymous with *dukulā*. In course of time it was identified with the silk and between the 12th and 16th centuries A.D. its original meaning began to be forgotten (Sandesara and Mehta, p.28; Sarkar, p.60; Ray, p.195).

Hemp receives mention in the *Śatapatha Brāhmana* (Ray, p.197)[7]. The fibre, which is inelastic and crushes easily, is derived for purposes of weaving from the bark of *Cannabis sativa*, *Crotalaria juncea* and *Hibiscus cannabinus*. The oldest hempen fragment from *Cannabis sativa*, dated to circa B.C.800, has been found at Gordion in Asia Minor (Geijer, p.8). In India, however, *Cannabis sativa*, characterised as true hemp, has been cultivated predominantly for the narcotic extract obtained from its leaves and flowers. Known as *bhāṅga*, *vijaya* in Sanskrit, *gañjā* in Hindi, Bengali and Persian, it is indigenous to all parts of India. As a source of fibre, it has been utilised only in Nepal (Roxburgh, pp. 545, 718). The most popular source for hemp in India has been the bark of *Crotalaria juncea*, Sanskrit *śaṇa*, Bengali *son*,. It is an annual plant cultivated in all parts of South Asia. The fibre in Bengal is whiter than that of Maharashtra because of the more rigorous processes of cleaning adopted. The history of *śaṇa* pre-dates that of jute in India. The term gunny, carrying the connotation of jute in modern times, was derived from

the term *goṇi*, a coarse cloth originally made from *śaṇa* (Roxburgh, p. 545; Watt, II, p.545).

In the case of *Hibiscus cannaibinus*, *mesta pāṭ* in Bengal, *ambaree* or *ambadi* in Maharashtra *Palungoo* in Madras, the bark has been utilised for its fibre, while the leaves have served as a comestible. An alternative term adopted in Bombay for *ambaree* was Deccani hemp to distinguish it from *Crotalaria juncea*, or Koṅkani hemp. In the hilly areas of the region known earlier as the Circars in present day Andhra Pradesh, this plant was called *Hibiscus collinus*, the vernacular term being *kanda gang* (Roxburgh, p.528; Royle, pp.253-55, 261)[8]. It is called *Hibiscus eriocarpus* in present times. In central India, Verrier Elwin records that the Bondas, Gadabas and Parengas spin fibre from the bark of *Calotropis gigantea*. This is *arka* in Sanskrit, *ak* in Hindi and *akado* in Gujarati. This is mixed with cotton and woven on simple looms. Both fibres can be dyed. This cloth is called *Keranga* cloth (Elwin, pp.27, 33,35)[9] (*Figs. 1 & 2a-2d*).

Jute fibre is obtained from *Corchorus olitorius* and *Corchorus capsularis*. The plants are native to various parts of India and have been exploited in the pre-industrial period. *Corchorus olitorius* is called *puṭṭā* in Sanskrit and *Pāṭ* in Bengali (Roxburgh, pp. 428-29)[10]. The reddish variety was called *bun* (wild) *pāṭ* in Bengal. Woven material was called *tāt*. The term for coarser cloths used for making bags was *choṭi*, while saris were referred to as *megila* (Roxburgh, p.429; Watt,II,p.545; Royle, pp. 241-42)[11]. The fibre from the bark of *Corchorus capsularis*, called *ghi-nalita pat* in Bengal, was diverted to the manufacture of gunny bags and cordage (Royle, p.242; Watt, II, p. 545; Roxburgh,p.429)[12]. Other terms that are used for this fibre include *narchā* and *nalitā*. Thomas Wardle makes a reference which may have a bearing on earlier usages. Bark of the twigs of a small

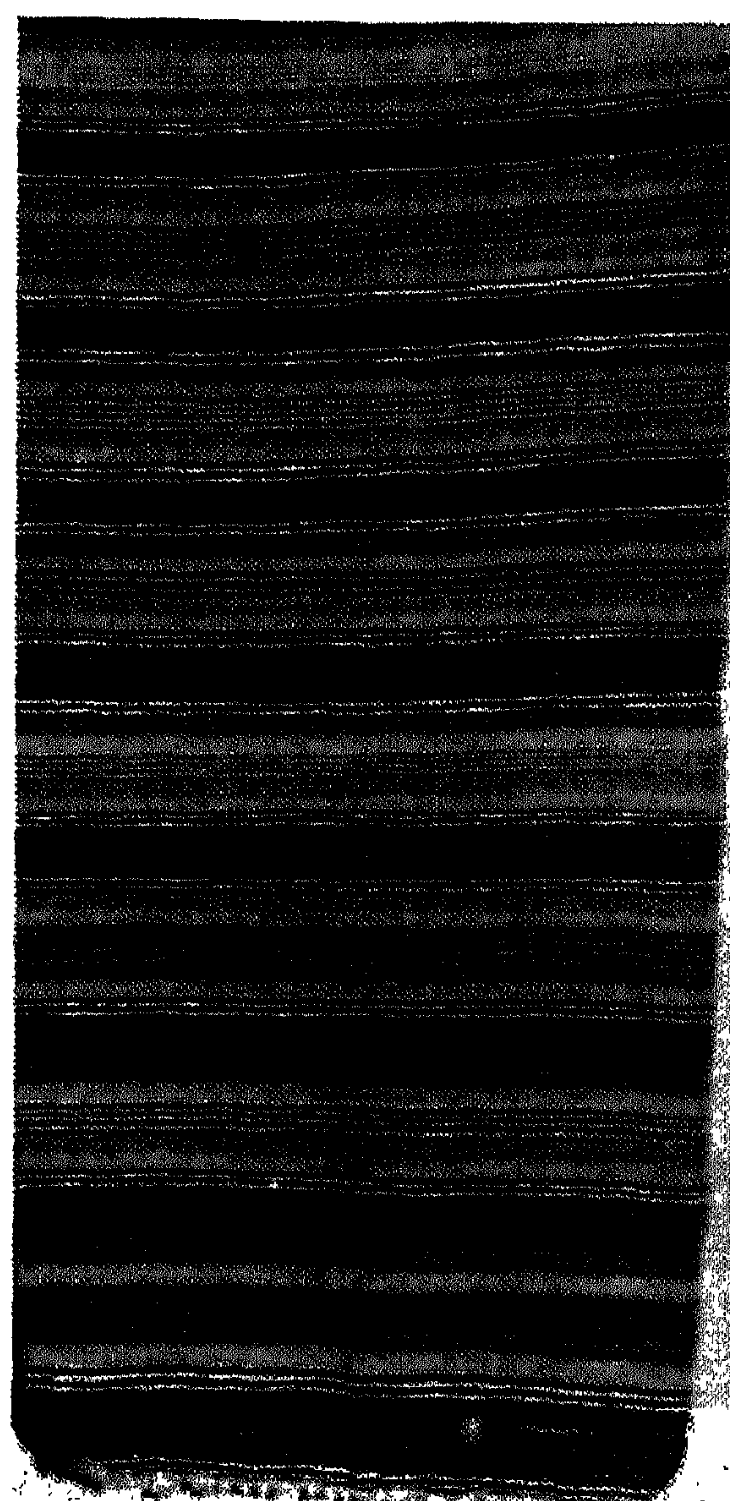


Fig. 1. Keranga cloth woven by Bonda women, District Korapat, Orissa. This is a sample of a female hip cloth. Men wear similar pieces as loin cloth



Fig.2a. Loom used in weaving Keranga cloth

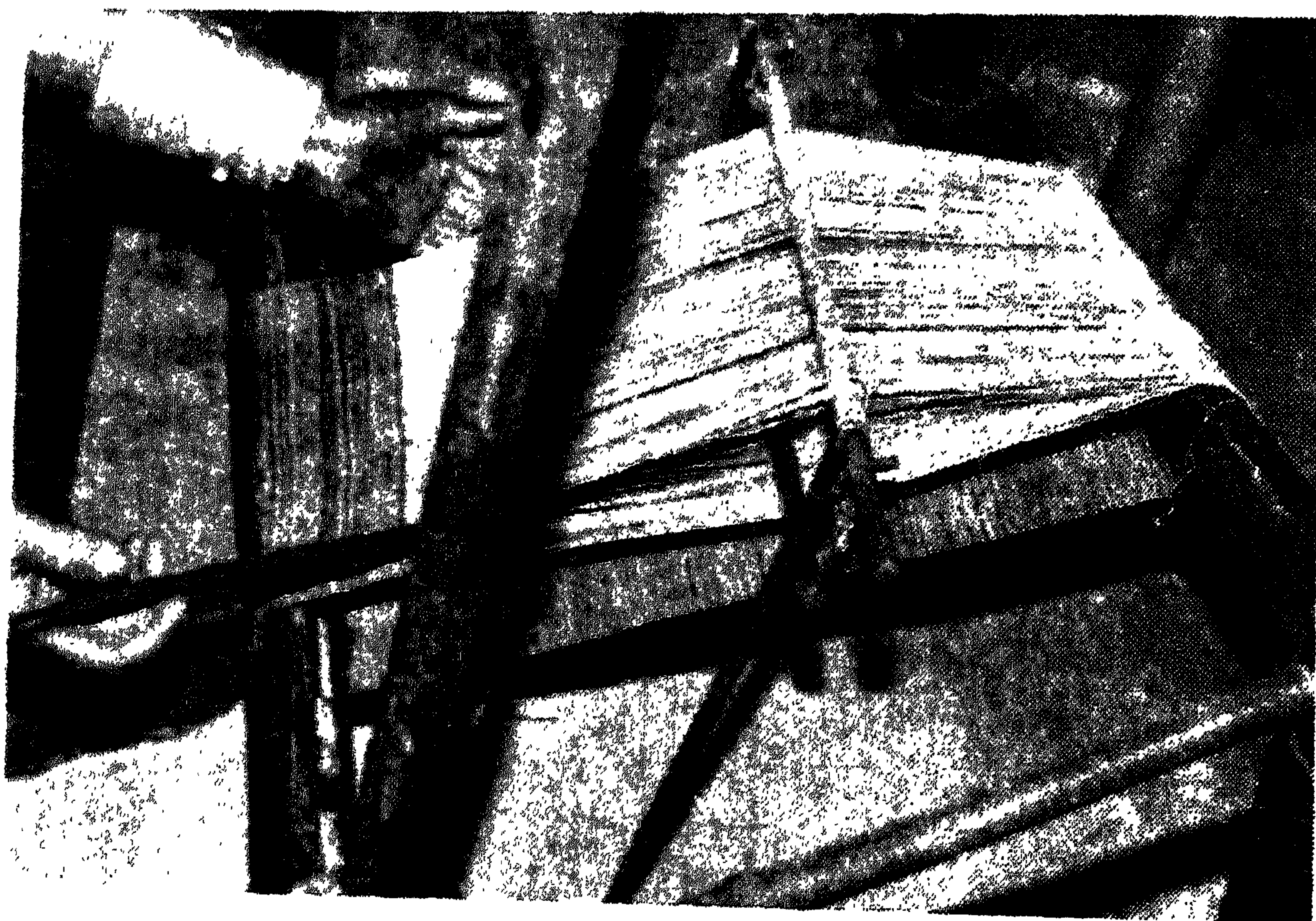


Fig.2b. Weaving process in Kerãnga cloth. Note heddle stick, absence of need, yarn wound around a stick which serves as shuttle and the continuous warp

bush widespread both in its cultivated and wild form in the hotter areas of India, called *Ulatkambal* in Bengali, *Abroma augusta*, Linn. *Sterculiaceae*, yielded a lustrous, and soft fibre, akin to hemp and jute but distinct from both. It was much valued as it could be used as a substitute for silk (Wardle,p.119; Watt, I,p.8, *Abroma augusta* Linn q.v).

The technology for the separation of jute fibre was simple. When the crop was ripe, it was cut down close to the roots. Separate bundles of the stems were made and these were left to steep in the water of some adjoining ditch. The bundles were

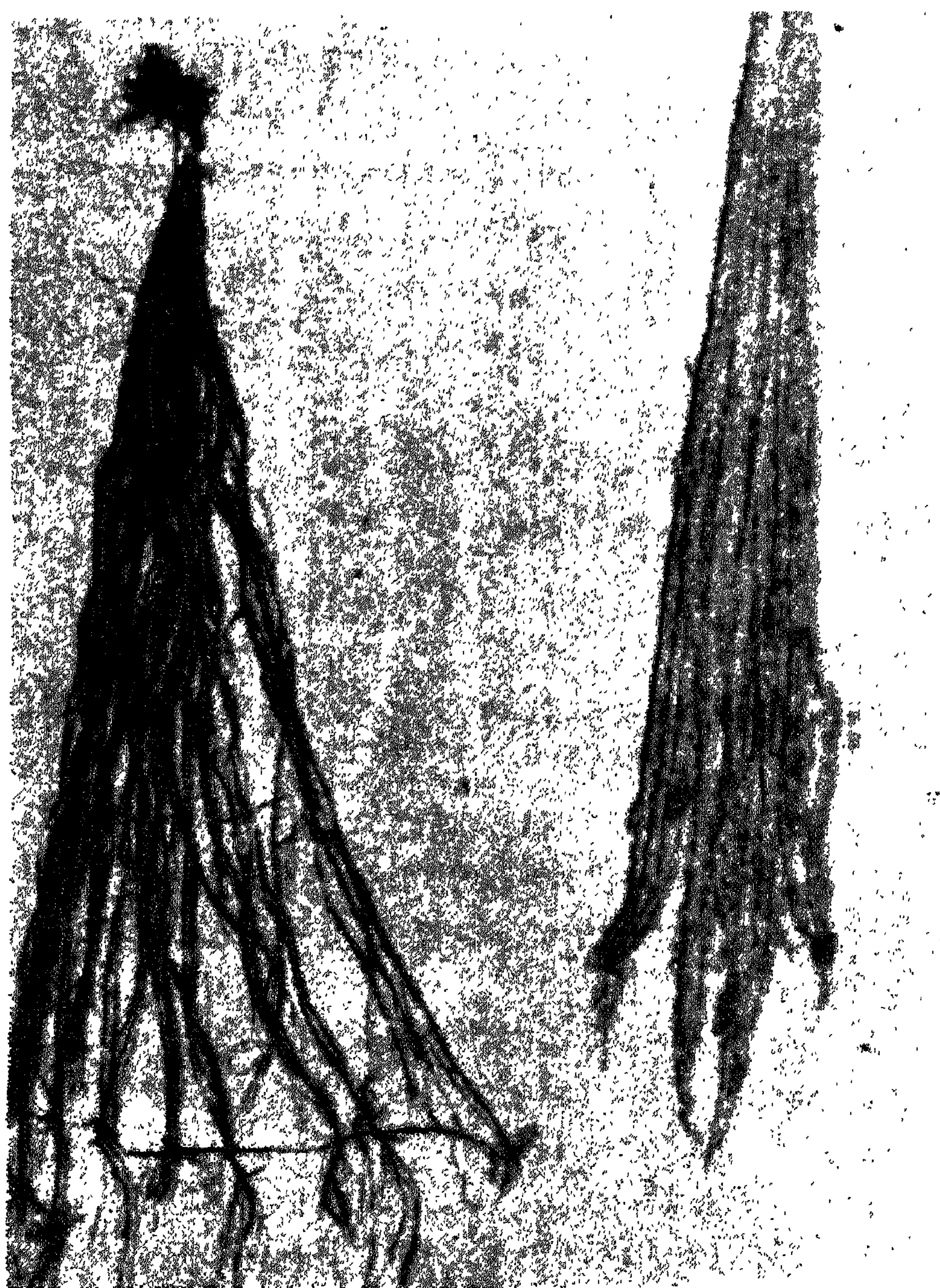


Fig.2c. Fibre from Calotropis gigantea, Kerāṅga. Photographs 2a-2c, Courtesy, Orissa State Museum, Bhubaneshwar

weighted down with mud. The process of decomposition was carefully watched, the bark being tested from time to time by scratching the surface with the fingernail. At the next stage the separated fibres would be vigorously beaten for cleaning (Royle, pp. 242, 248-49).

The last major group among bast fibres has been associated with the plant *Boehmeria nivea*, commonly referred to as ramie or China grass. Regional variations in nomenclature were *schou-ma* in Chinese *Poah* in Nepal, *rhea* in Assamese (Balfour, II, p.403; VII, p.403)[13], *kaṅkhura* in Bengali and *ramie* in Malay. Forbes Royle notes that circa, 1855 *rhea* was not a commercial crop in Assam. It was grown around their homes by Dooms, members of the fisherman caste, and used by them for their needs (Royle, p.345). The preparation of fibre was a tedious process. Despite the silkiness of individual filaments, the inherent stiffness of the fibre made it difficult to twist, making its spinning an arduous process (Watt, I.p. 474).

In Darjeeling, Dehra Dun and other places in North India, a related plant, *Boehmeria puya* Royle, was grown, *puya* fabric being woven from this fibre. The fibres derived from *Boehmeria salicifolia* and *Boehmeria utilis* were used for making rope (Balfour, II,p.403). These references to *ramie* as identified above, make it clear that the woven material could not have been of very high quality.

However, in the *Rāmāyaṇa*, *ramie* or nettle cloth receives high praise for its fineness and beauty. Samples of *ramie* in Japanese collections are also of a high

quality. The above reference may be taken to imply *Urtica heterophylla*, the *Horoo surat* of Assam, the Nilgiri nettle of South India and *herpah* of Bhutan. This plant, the bark of which yields an abundance of fine, white glossy silk-like fibres, grows in Burma, Assam, the Himalayan foothills up to Dehra Dun, Southern Konkan, Karnataka and coastal Kerala. The nettle cloth mentioned in the *Rāmāyaṇa* may have been derived from the fibre of this plant (Watt. I, p. 472; Royle, pp.366-367). Varrier Elwin noted that among the tribal groups of the North-East, the Monpas, Sherdukpens and Idu Mishmi wove fibres derived from *Boehmeria nivea* and other of nettle origin into a cloth which was made into jackets. These were so strong and stiff that they could serve as a kind of armour (Elwin, pp. 68-69, 131).

In his seventeenth century diary, Streynsham Master refers to a textile called *herba*, while an eighteenth century French commercial dictionary mentions a bast fibre called simply *ecorce d'arbre* (bark of tree), said to stand midway between silk and hemp in its attributes. It was mixed with silk to weave the cloth variety called *gingham*. In view of the affinity between Rhea and fibres such as wool and silk pointed out by G.Watt, this fibre noted by the Europeans may be taken as a variant of *Boehmeria nivea.*[14]. It could equally well be associated with *Ulatkambal*, mentioned by Thomas Wardle.

Wool

Woollen fabrics have a tradition as old as that of bast fibres in India. Panini refers to the category of woolen garments as aurna/aurnak[15].By the opening years of the Christian era not only was sheep's wool differentiated from that of the goat but even in the latter category, a line was drawn between the fibres derived from the domesticated variety and its wild counterpart (Varadarajan, 1984). The properties of wool had a bearing on its usage as a fibre. Wool is elastic and its fibres have a rough surface. This is caused by an external layer of microscopic overlapping scales. Wool can absorb 30% of its own weight as moisture, and when wet it generates heat. It can be stretched 30% beyond its normal dimension and still spring back to its original configuration when released. It is wrinkle resistant and has high powers of insulation. It is for this reason that desert dwellers wear wool to keep the heat out (Brown, p.213). These properties explain why wool was accorded a high ritual status in early texts.

Unlike flax, wool requires little preparation for spinning. It can be spun directly after carding. However, for high quality items like *Kāni Pas̍minā* it was scoured and graded prior to carding and spinning operations [16]. Since wool possessed a natural fatty material washing was essential prior to dyeing. When placed on the loom warp ends had to be spaced to prevent or minimise the tendency to catch, cling or lock together on contact. However, once positioned safely wool keeps in place and this has favoured its usage in tapestry weaving.

It is therefore, not surprising to note the double interlock a variant within the tapestry reportoire, developing in relation to *Kāni Pas̍minā* in Kashmir[17].

Owing to geographical and environmental factors, wool, over the major portion of India, is of inferior quality. Apart from Kashmir, Kutch and Saurashtra in Gujarat, and centres in Western Rajasthan, have developed items of variegated



Fig.3a. Loom of Meghwal community. Continuous goat hair warp, no reed. Two weavers sit on either side of the loom. There is no pit. The weft yarn is wrapped around a stick about $2^1/_2$' in length. This is slipped through each shed as it is formed. The single shaft consists of a series of heddles passing through every alternate end. This is mounted on a heddle rod balanced on two sets of longitudinal poles. The upper rod slides alongwith its stand as weaving progresses. The weavers also move forward as weaving advances

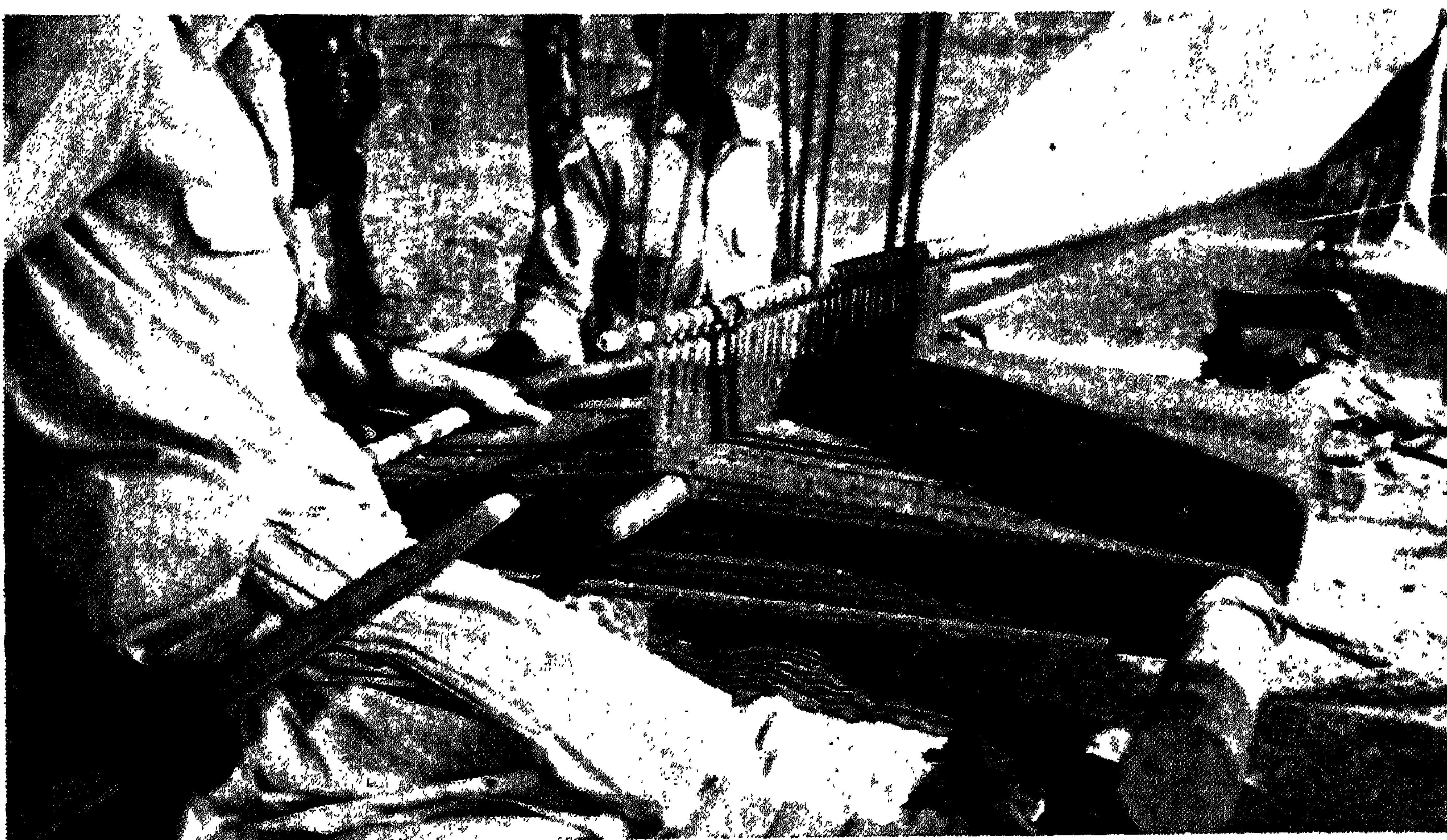


Fig.3b. Shed formation. In order to create a shed the suspended heddle shaft is slightly lifted. A flat stick is inserted in the small shed formed.This stick is then turned on its side to get a wider opening. The counter shed is formed by taking out the flat stick and bringing the shed rod closer to the heddle shaft. Although there is a continuous warp, usually the full warp is stretched out horizontally

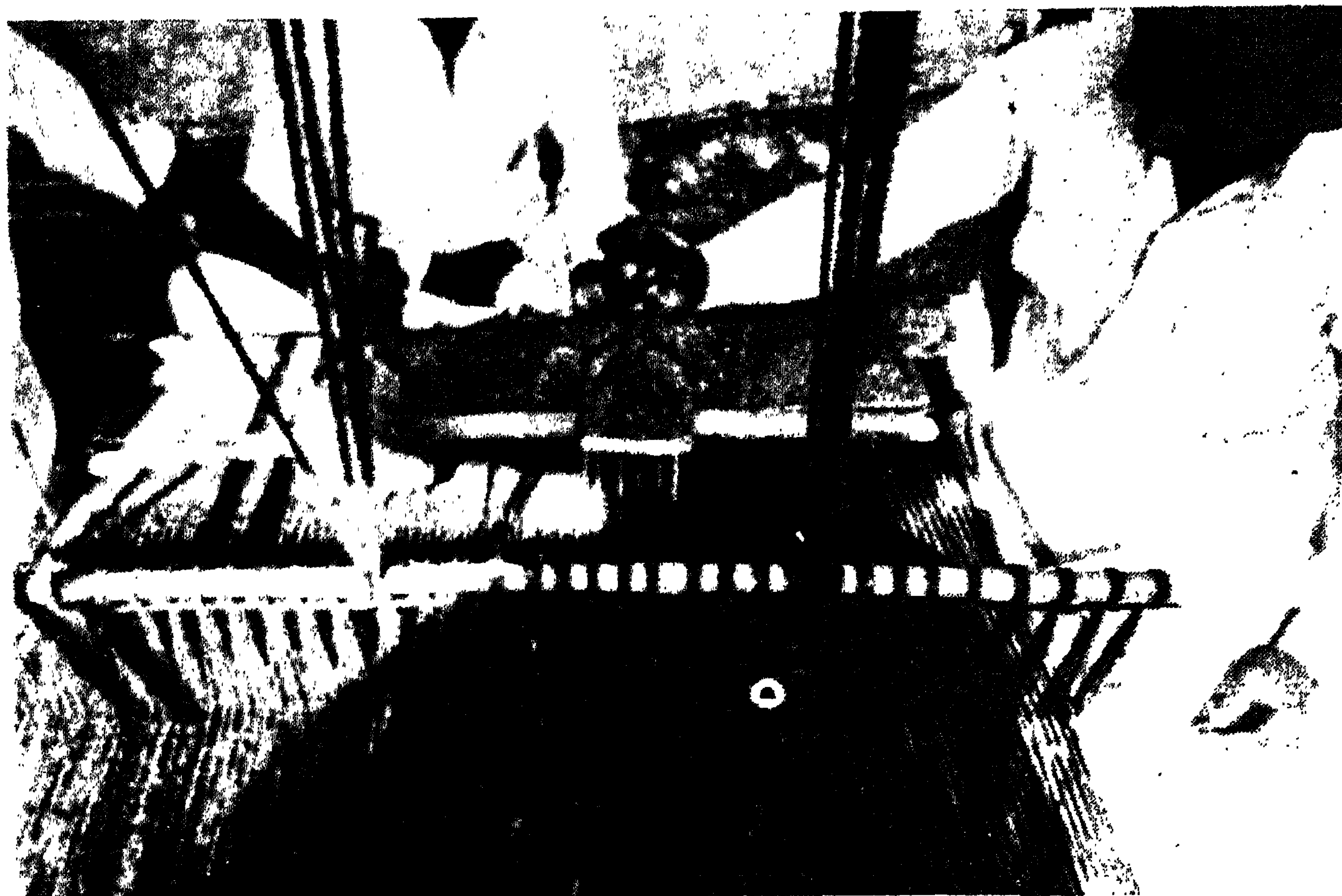


Fig.3c. After completion of each pick the weave is beaten in by two pāñjā beaters. Figs.3a,b,c were taken at a fair organized for Adivasis at Sanskar Kendra, Ahmedabad, February, 1992. The two weavers, Amba Ram and Sanook Kastura Ram, hail from Gam Megha Par, Post Rama, Jilla Jaisalmer

design in polychrome hues using rough quality sheeps' wool. In areas of low to deficient rainfall in Northern India, the camel is an important domesticated animal, but the hair of the Indian one- humped dromedary, unlike that of the Bactrian two-humped animal, is not altogether suitable for weaving. The Meghwal Community in Rajasthan weave a floor covering in which the warp is hand spun goat hair, and the weft, camel hair (*Figs. 3a-3c*).

Silk

The silk tradition in India is a very early one and by the time of the compilation of the *Arthasastra* [18] there had emerged a clear sense of the distinction between Indian and Chinese silk, and, within India, there was an association between the colour and the quality of local bi- and multi-voltine cocoons of *Bombyx mori* (mulberry feeding moth), and that spun from the cocoon of the multi-voltine *Atticus ricini* (Eri). Wild silk is reeled from *Antherea mylitta* (Tasar), *Antherea assamensis* and *Saturnia assama* (Muga). Eri is also obtained from the cocoons of the moth *Philosamia cynthia* (Wardle, pp. 5-6, 55; Nanavaty, pp.193-210)[19]. Bengal and Assam have been the traditional centres for mulberry silk. Muga and Eri are restricted to Assam, while Tasar has been produced in Bengal, Orissa, Bihar and Andhra Pradesh.

Mulberry silk has a tradition of being woven even in areas ignorant of its cultivation, but the weaving of wild silk has tended to be more localised being

generally restricted to the actual regions where the raw material was produced. (For further details see Varadarajan, 1986, pp.189-198; 1988, pp 561-570).

Cotton

The cradle of cotton cultivation appears to have been the Northwestern part of South Asia. There seems to have been two species, *Gossypium arboreum* and *Gossypium, horbaceum*. Three samples of cotton, dated circa B.C. 1760 have been found in Mohenjodaro. Two items constitute the base fibre for string but there is also a small 34 count cotton woven fragment comprising 60 ends and 20 picks per inch. A portion of one of the strings tested showed that the cotton was of the *G. arboreum* variety. Both varieties existed in their perennial forms in areas with adequate water and warm temperature. The appearance of the annual variety of *G.herbaceum*, which could be diffused over a larger area is dated circa late 6th early 7th centuries A.D. and its earliest appearance is associated with the Turfan region of Sinkiang. It soon became the predominent species in India as well [20]. The highest achievement in the area of textiles in India are associated with manipulation of this fibre.

Indian Predelictions in colour and levels attained in Dye Technology

By and large, pre-Islamic Indian predelictions in colour tended towards a sober palate [21]. The range of colour in cotton dyeing was based on blue and black from *Indigofera tinctoria*, black from iron acetate or a ferrugenous earth from Kutch called *Khayo*, red from either *Rubia cordifolia*, *Morinda citrifolia* or *Ventilago madraspatana*, yellow from *Curcuma longa* (turmeric), *Punica granatam* (pomegranate rind) or *Mangifera indica* (mango bark extract). Different shades could be obtained by combining individual dyeing procedures. Tanning and mordanting were very important pre-dyeing operations for cotton[22]. In Egypt mordanting in linen was practiced but the importance of tanning for fixing of the mordant was mastered in India [23]. There is some variation in methods of dyeing and dyes used in the range of fibres such as silk and wool [24]. In the case of silk, efficient degumming is essential for success in subsequent dyeing operations. Generally, the yarn rather than the woven fabric has been dyed.

Techniques of patterning achieved through variation in colour are associated with the practice of *ikat*, *plāṅgī*, painting or block printing. Batik as practiced in Indonesia involving usage of cold dyes is alien to the Indian tradition. However, in Mundhra, Kutch, there is a tradition of resist dyeing in which the resist paste, *minia*, is made of a mixture of top soil of goats pens which includes goats droppings, *gugul* local incense resin, olibanum, Fuller's earth and gum made into paste consistency which withstands hot dyeing. The colour palette comprised red, white and black. (Oral information: Shri Khodidas Parmar, Bhavnagar.) The earliest methods of dye patterning were accomplished by resisting through knotting of either the yarn as in *ikat*, or the finished product, as in *plāṅgī/bandhanī*, prior to processes of colouration. Fabrics could also be dye-patterned either by means of painting, or by stamping of mordant and resist with wooden blocks, the end product was called

Kalamkari or *Cit* [25]. Tie & dye may be practiced on wool, silk and cotton. In India painting and stamping has tended to predominate on cotton.

Indian Loom Technology

The loom has been defined by Dorothy Burnham as, "any device for weaving on which the warp may be arranged and openings for the passage of the weft formed through it by a shedding mechanism" (Hoffmann, p.7). The predominant loom in India has been the pitloom of the horizontal counter-balance treadle type (*Fig.4.*). Broadly speaking, on the basis of ethnological evidence, the evolution of the Indian loom could be postulated as follows: at the first stage the loom may have had shed sticks and heddles (*Figs. 3a, 3b.*). Next came the introduction of the reed (*Fig.4*), shaft, treadle and, perhaps, the barrell dobby [26] (*Fig. 5.*).

The loin or body tension loom is used in the northeastern part of the country. It is a very early loom type used extensively in East and Southeas* Asia in which the weaver regulates tension by moving backwards or forwards as required in course of weaving. This movement releases the warp threads and also facilitates the separation of the sheds (For details, *see* Shirali, pp. 83-87) (*Figs. 6a-c*).



Fig.4. Horizontal counter balance pit loom with shafts and treadles. This loom is positioned within the living accommodation of the weaver and, therefore, allows for integration with other domestic activities and pastimes. Note the narrow reed. This loom is used for weaving tribal loin cloths. Weaver, Sri Rama Bhai Wanker, Chota Udepur, Gujarat

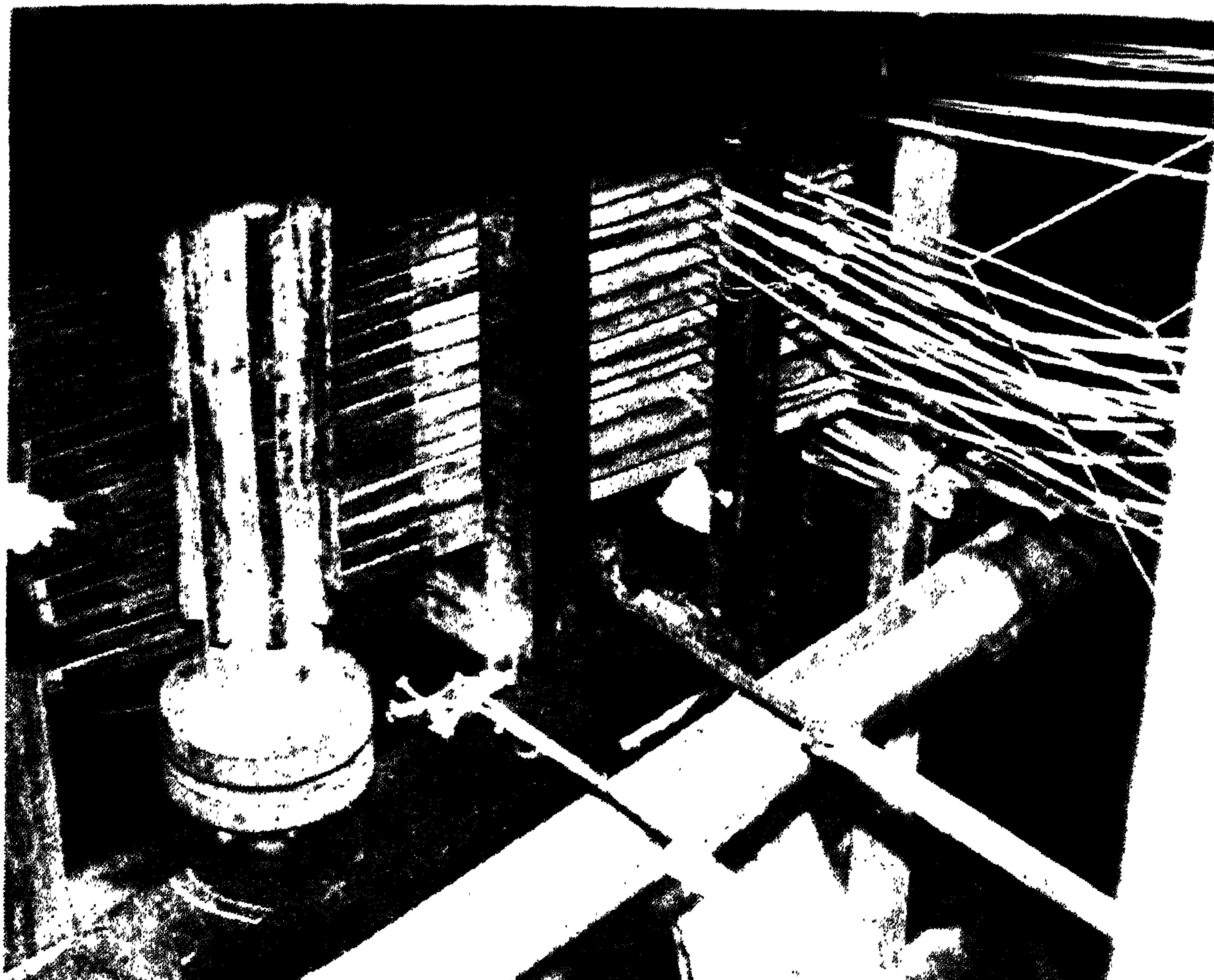


Fig.5. Barrel dobby mechanism. The loom used for weaving Karvathi Kati dhoti. Photographed at Suraj Mela, 1987

The loom used for Patola (*double ikat*) weaving in Patan, Gujarat, receives support from above and the sides. It is bereft of a treadle mechanism. It is a single harness loom with provision for two sheds. Every alternative warp end is threaded through a half heddle. Thus the shedding arrangement is based upon the division of the warp ends into two units. The shed rod is used to form one shed and half heddles for the formation of the second. These groupings of odd and even ends interlace alternately in course of weaving. The weaving sword helps in extending each shed opening and is used for beating in the weft. The resultant weave is an even tabby (*Figs. 7a-c,8*).

Ornamentation on the loom can be achieved by introducing variations in color while maintaining a simple tabby weave (*Fig.8*). Similar effects can be achieved by using double cloth techniques in which warp ends are manipulated at two or more levels by relevant shafts and heddles. An example of this technique may be found in the *khes* [27] of Punjab (*Figs.9a-b.*). Items similar in patterning and technique and dated between the 12th and 16th centuries in the Dumbarton Oaks, collection, U.S.A., have been assigned an Egyptian provenance. This corresponds to the period between the Ayyubid and Mamluk dynasties thus reinforcing a Near Eastern origin for the sub- category called *majñu* in India (Thompson, pp. 35-36; Lamm, p.60, plate XXA, B).

However, the double cloth technique also appears to have enjoyed an indigenous base. This is evidenced in the Deccani double coloured *Pitāmbar sāri*, a silken ritual

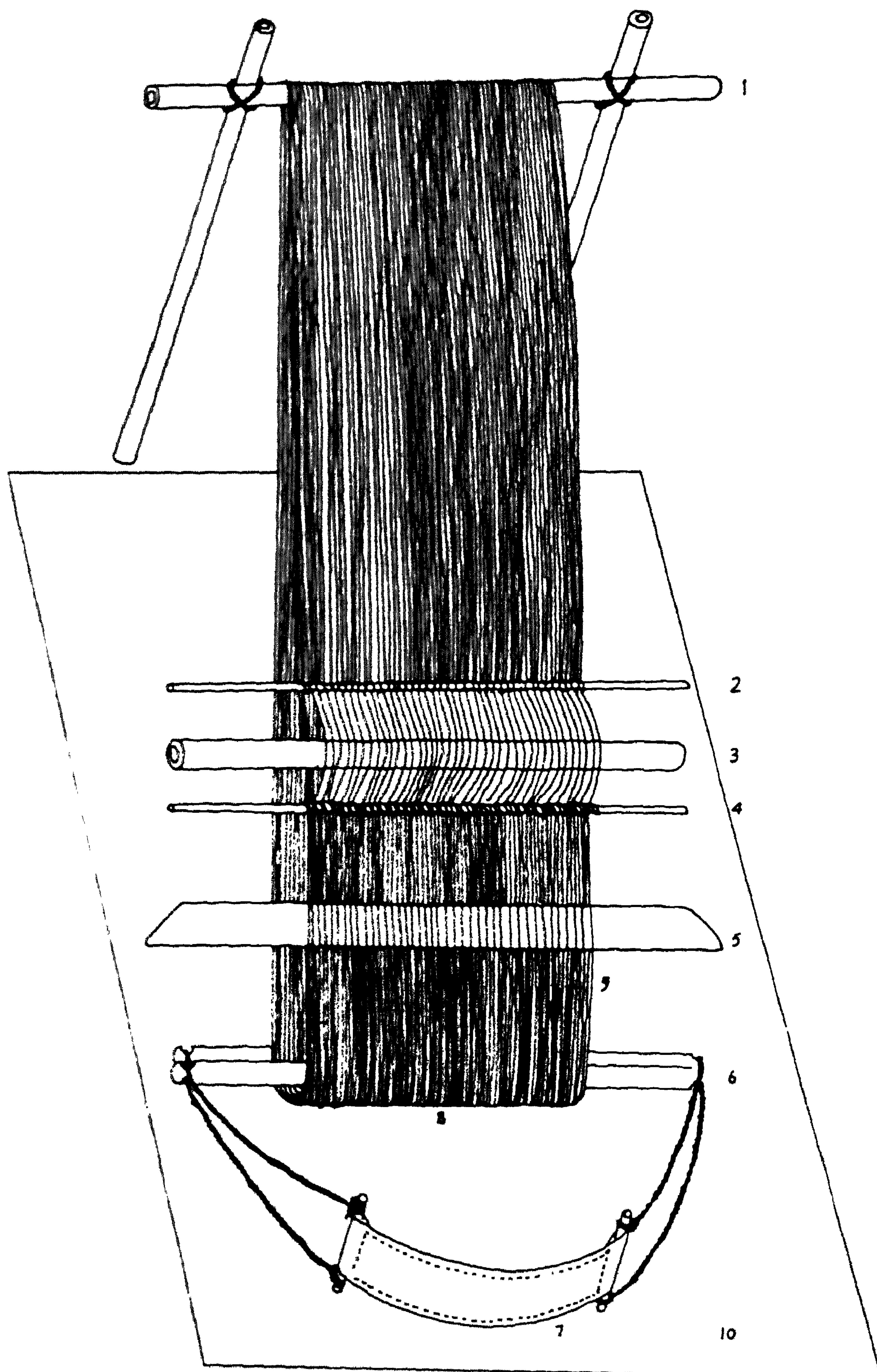
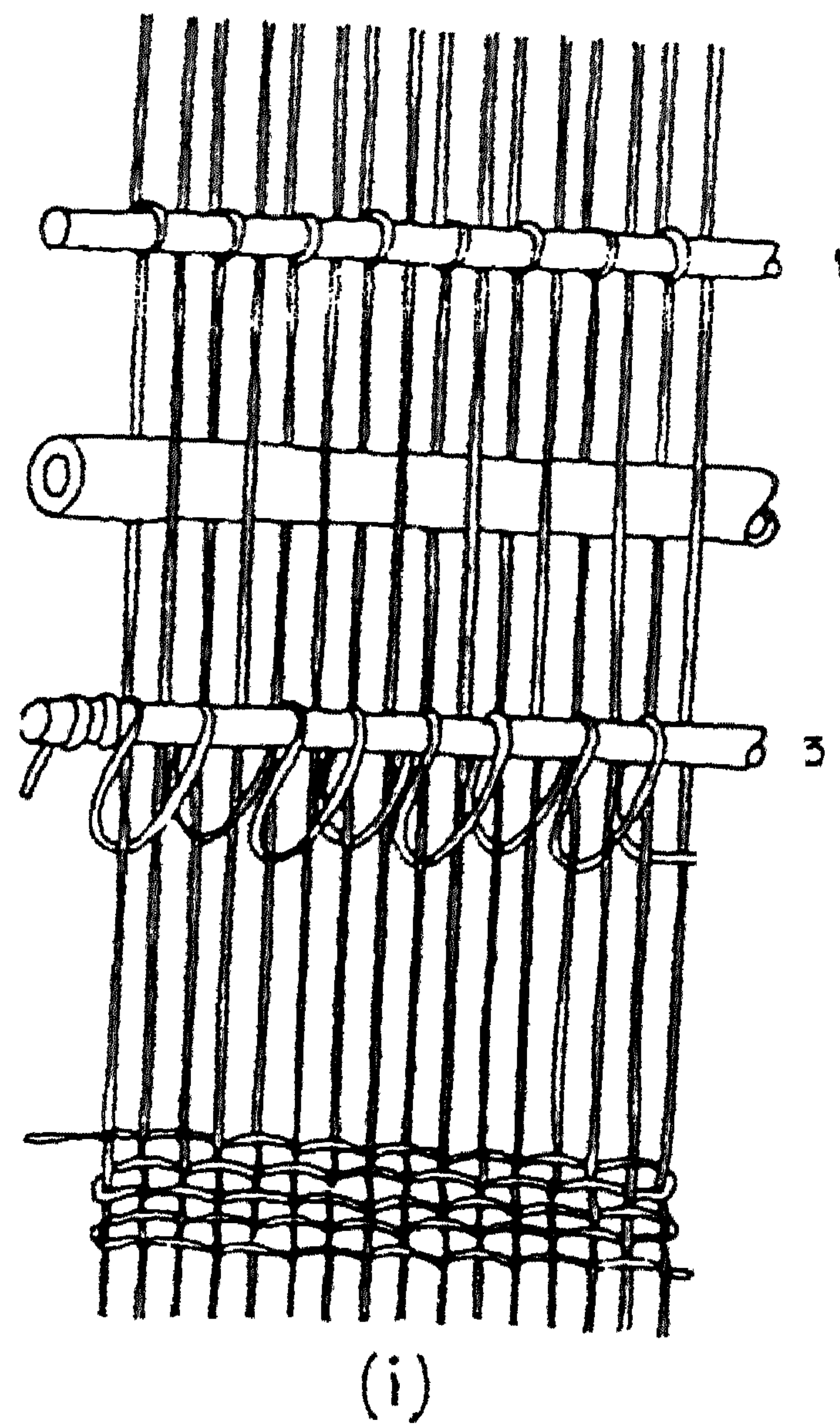


Fig.6a. Loin loom and loom parts. (1. Bamboo which serves the same purpose as the warp beam in a horizontal loom, 2. Thin bamboo rod which acts as a lease rod, 3. Bamboo shod stick, 4. Thin bamboo heddle stick which holds the yarn heddles, 5. Wooden beater, 6. Wooden rods which serve the same purpose as the cloth beamin a horizontal loom, 7. Leather back- strap, 8. The continuous warp, 9. The woven fabric, 10. Mat spread on the floor on which the weaver sits



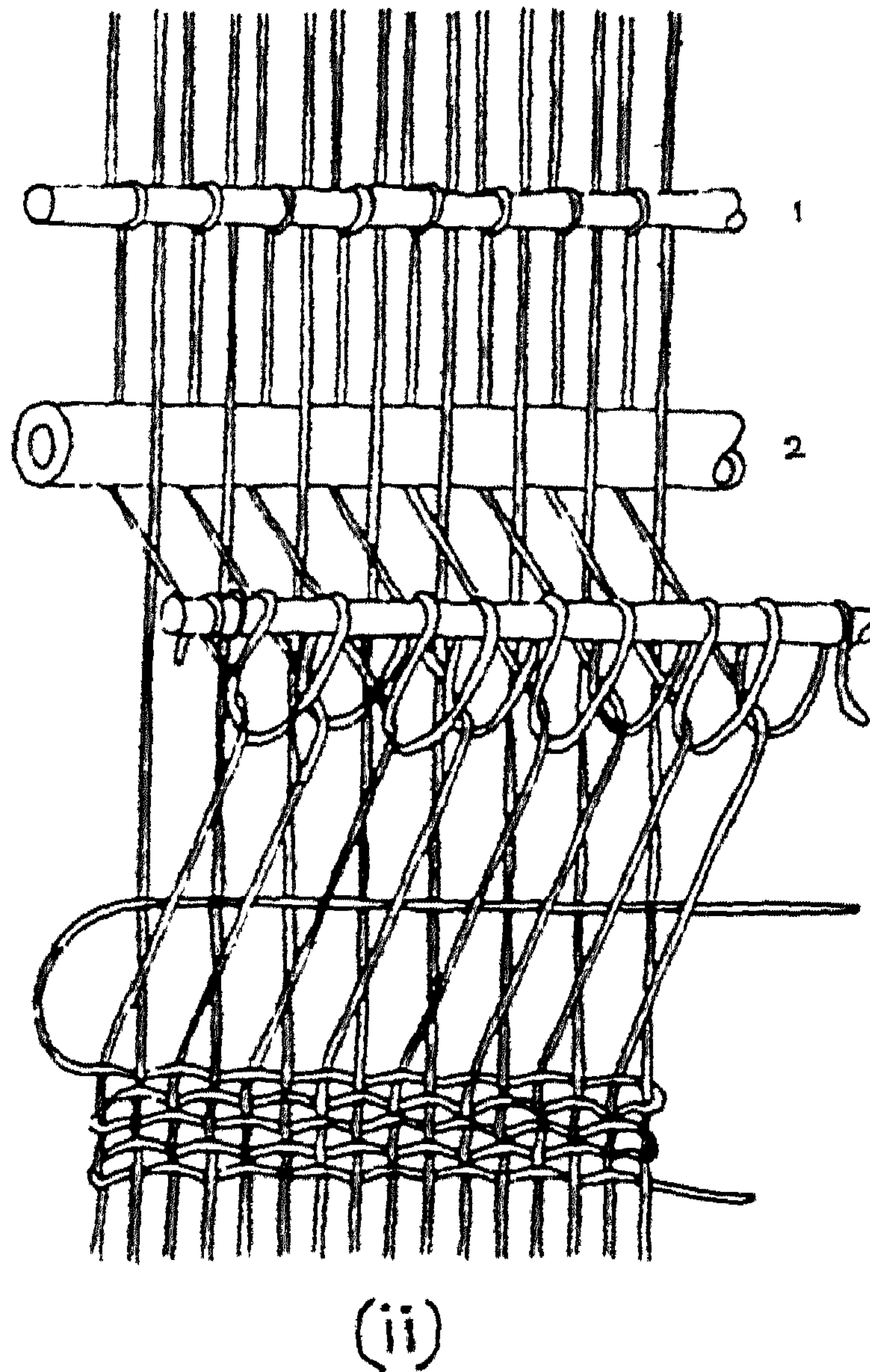


Fig.6b. Change of shed in loin loom.
(i) 1. Lease rod, 2. Bamboo shod stick, 3. Heddle rod, 4. Yarn to make the heddle, 5. Weft
(ii) 1. Lease rod, 2. Bamboo shod stick, 3. New position of the heddle rod, 4. Weft.
6a,b from Aditi Shirali's, Textile and Bamboo crafts of the Northeastern Region, Ahmedabad, 1983, pp.86-87



Fig.6c. Shrimati Lungham Chothe of Chandel, Manipur, domonstrating weaving on loin loom. Photographed at Craft

garment in which each side of the *sāri* presents a completely different colour field (*Fig.10*). However, the multiple cloths which evolved in the Near East have been absent in the Indian tradition.

One of the characteristics of the Indian loom has been the intensive use of shafts and treadles to achieve extra warp and weft patterning. For extra warp however, an ingenious device, the barrel dobby is much in evidence today. The dobby was patented in England but its roots may well lie in shaft and peddle devices used in extra warp ornamentation as in the *Paiṭhāni loom*, Maharashtra.

For narrow weaving as in borders, *Pāgris*, and for cross borders, looms with multiple shafts have proved popular solutions (*Figs.11a-c*). For weaving of *newar* and *patti*, used in providing the base on bed frames and for winding around the calves of persons having to stand for long periods, variations of the fixed heddle and looms with shafts have been used (*Fig 12.*) Such looms are in operation to this day in Wadhwan, Gujarat. Tablet weaving (*Fig.13*) is used as a finishing technique for *dhablas*, used as shawls or as body garments in Gujarat. It also appears to have been utilised in the weaving of tapes (*Fig.14*) used for tying bundles of manuscripts of a religious nature.

Fabrics can also be ornamented by the *jāmdāni* (*Fig.15a,b*), slit, single and double interlock as also the dovetail tapestry techniques (*Figs.16a-d,17a-b.*). None of these methods of weaving involve usage of elaborate loom procedures. The investment is in terms of manual skill. *Jāmdāni* and tapestry both pre-date the introduction of the Islamic repertoire in weaves. In *Jāmdāni*, which falls under the category of *Supplementary weft inlaid*, pattern ends are manually lifted with the pattern weft and ground weft positioned within the same shed (*Fig. 15a-b*). Major centres of *Jamdani* have been Dhaka, Tanda, Uppada and Paithan.

Slit tapestry, an early technique associated with Coptic tapestry, is found in the *pānjā dari* (*Fig.18*); single and double interlock (*Fig.16 b.c*), occur in Kani

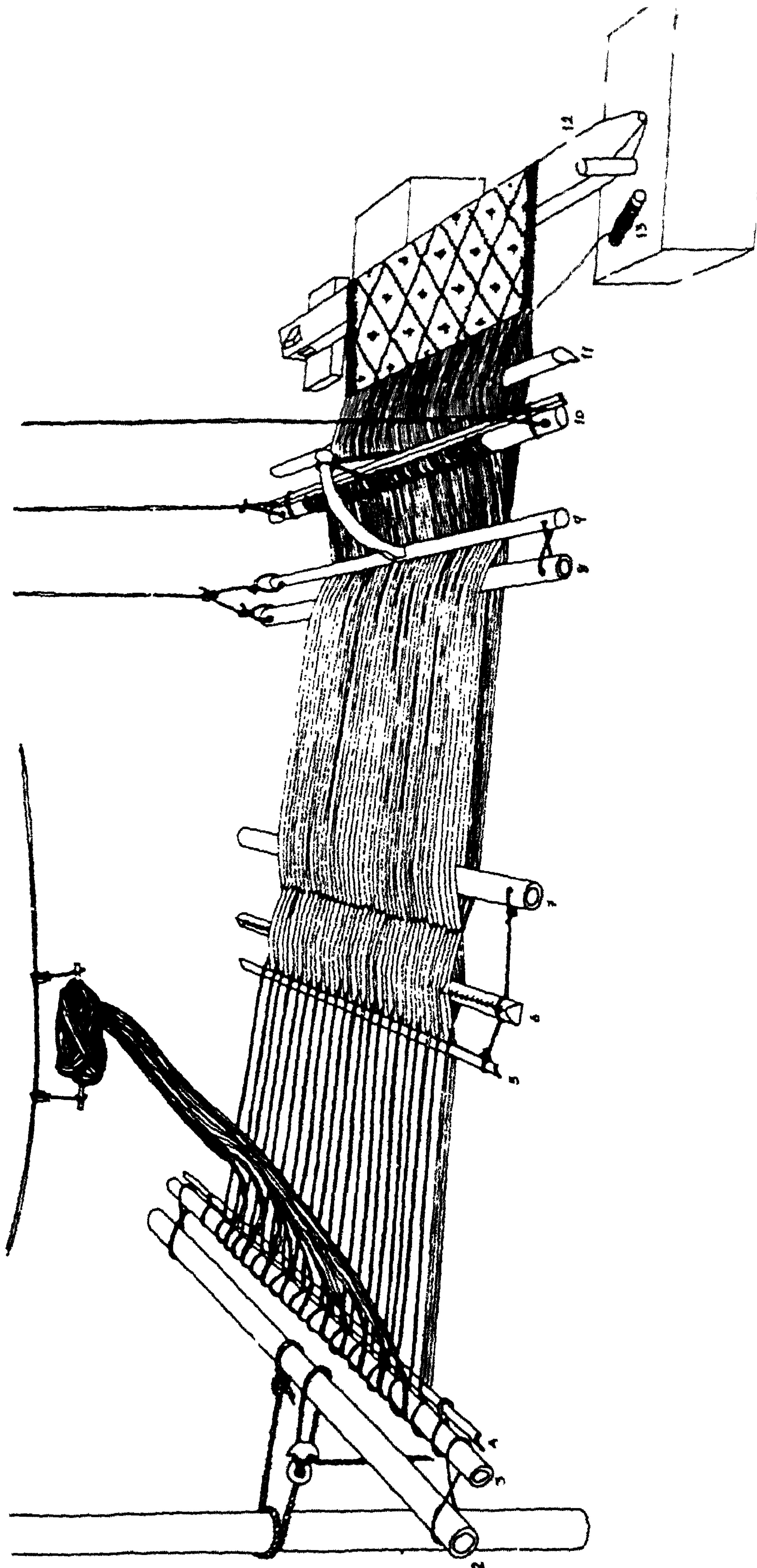


Fig.7a. Pāṭolā Loom and parts. (1. Pole for fastening the loom, 2. Warp beam, 3. Ditto, 4. Stick, 5,6,7 Cross mechanism with indented stick, 8. Shed rod, 9. Pressure bar with handle, 10. Heddle rod mechanism and heddles, 11. Sword, 12. Breast beam, 13. Shuttle)

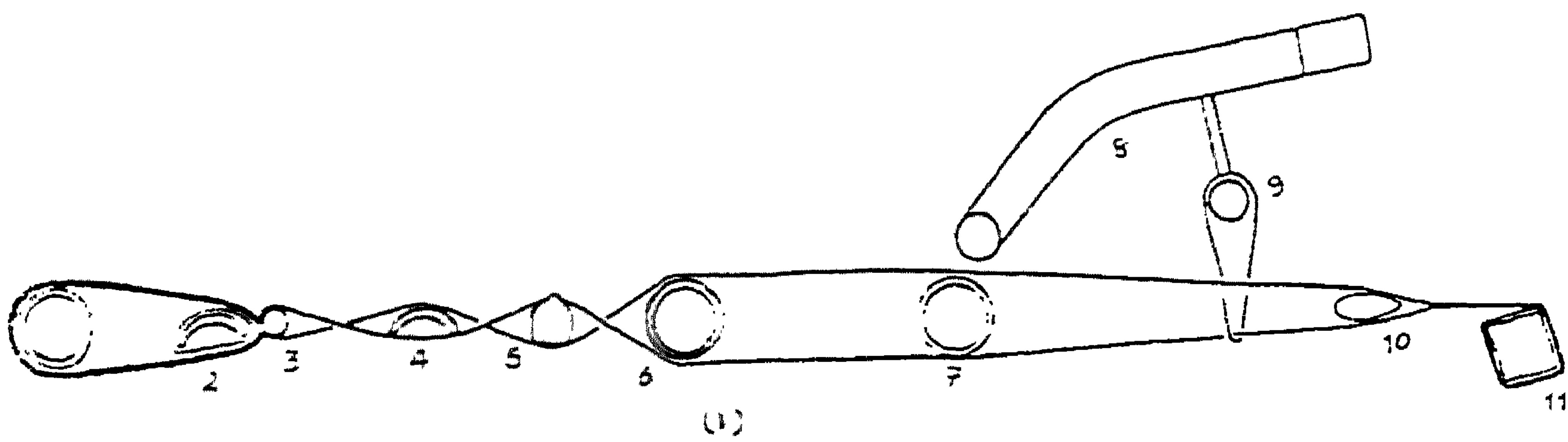


Fig.7b (i). Pāṭolā Loom, cross section of shedding mechanism, shed. 1. Warp beam, 2. Stick, 3. Ditto, 4,5,6. Cross mechanism with indented stick, 7. Shed rod, 8. Pressure bar with handle, 9. Heddle rod mechanism and heddles, 10. Sword, 11. Cloth bea

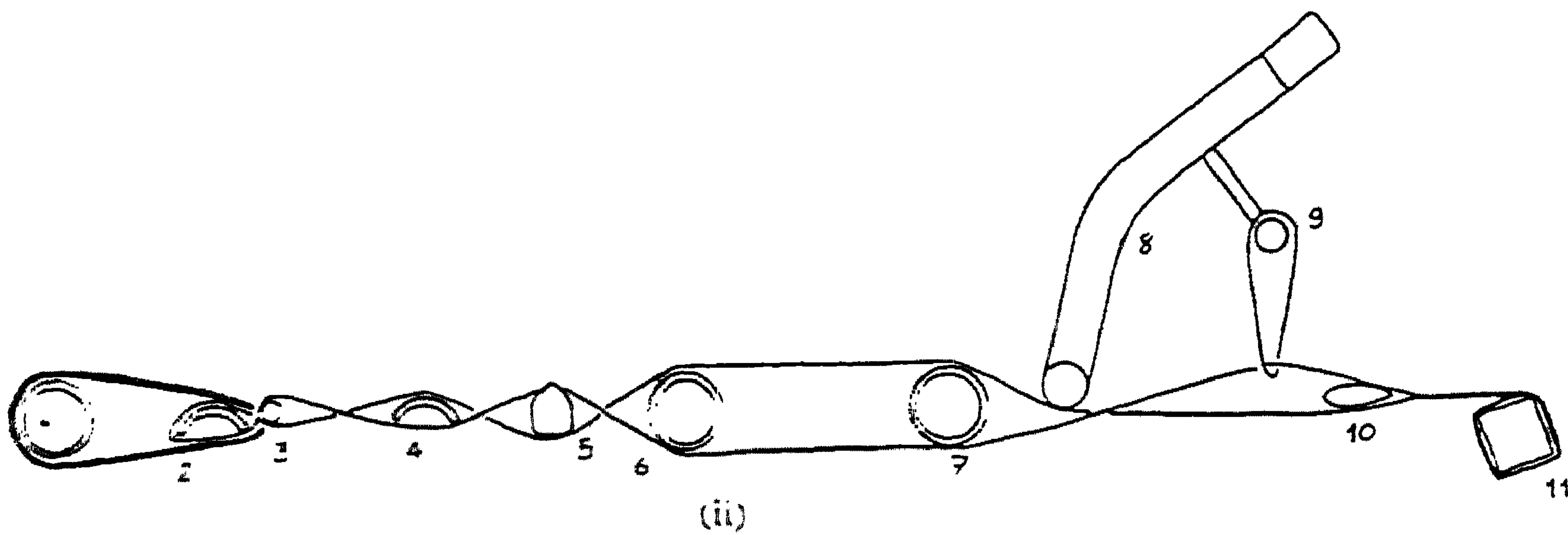


Fig.7b (ii). Pāṭolā Loom, cross section of shedding mechanism, counter shed. 1. Warp beam, 2. Stick, 3. Ditto, 4,5,6. Cross mechanism with indented stick, 7. Shed rod, 8. Pressure bar with handle, 9. Heddle rod mechanism and heddles, 10. Sword, 11. Cloth bea

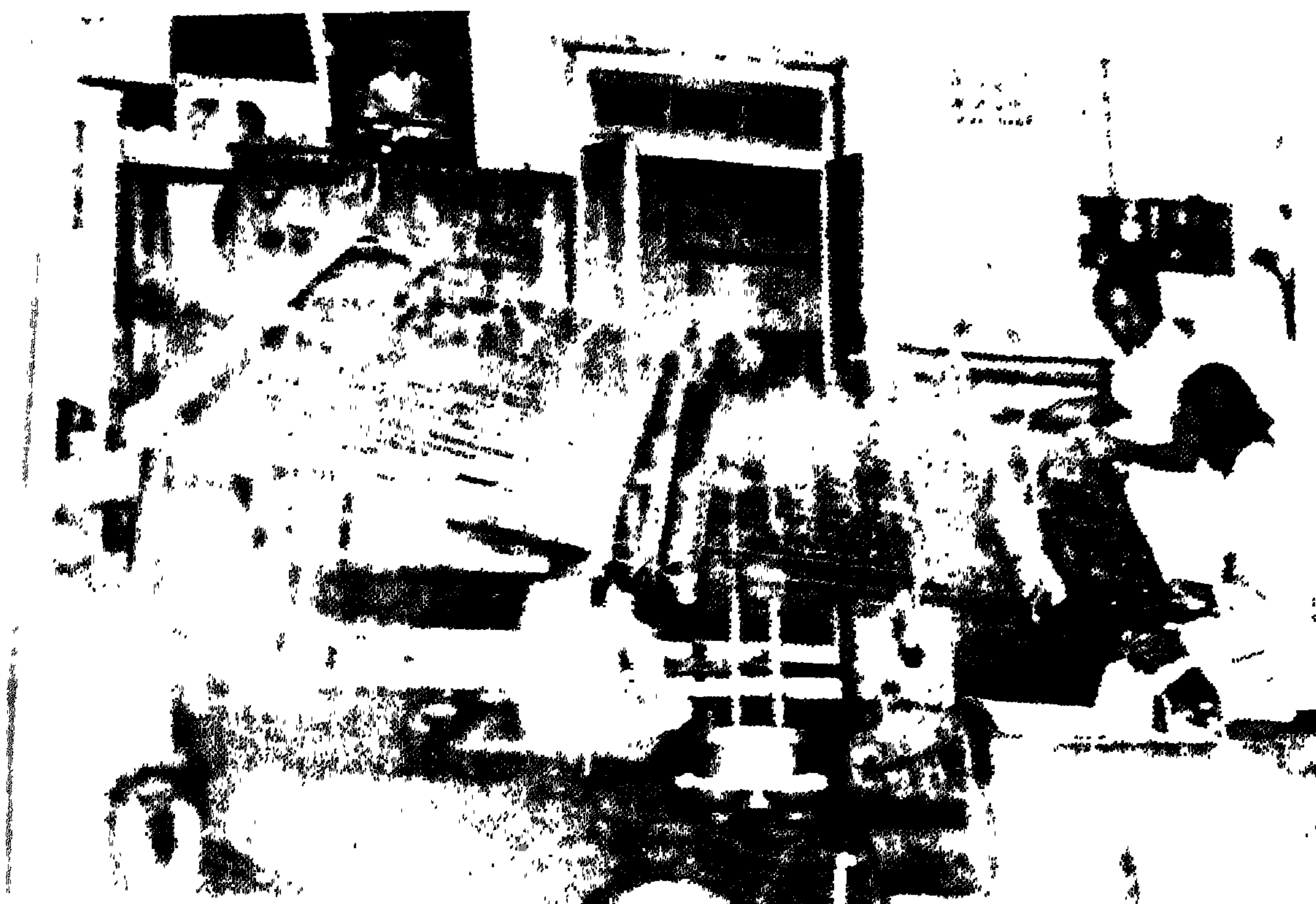


Fig.7c. Pātolā loom and work area. Operated by family of Sri Chotulal Salvi, Patan, Gujarat. Photographed in September, 1977

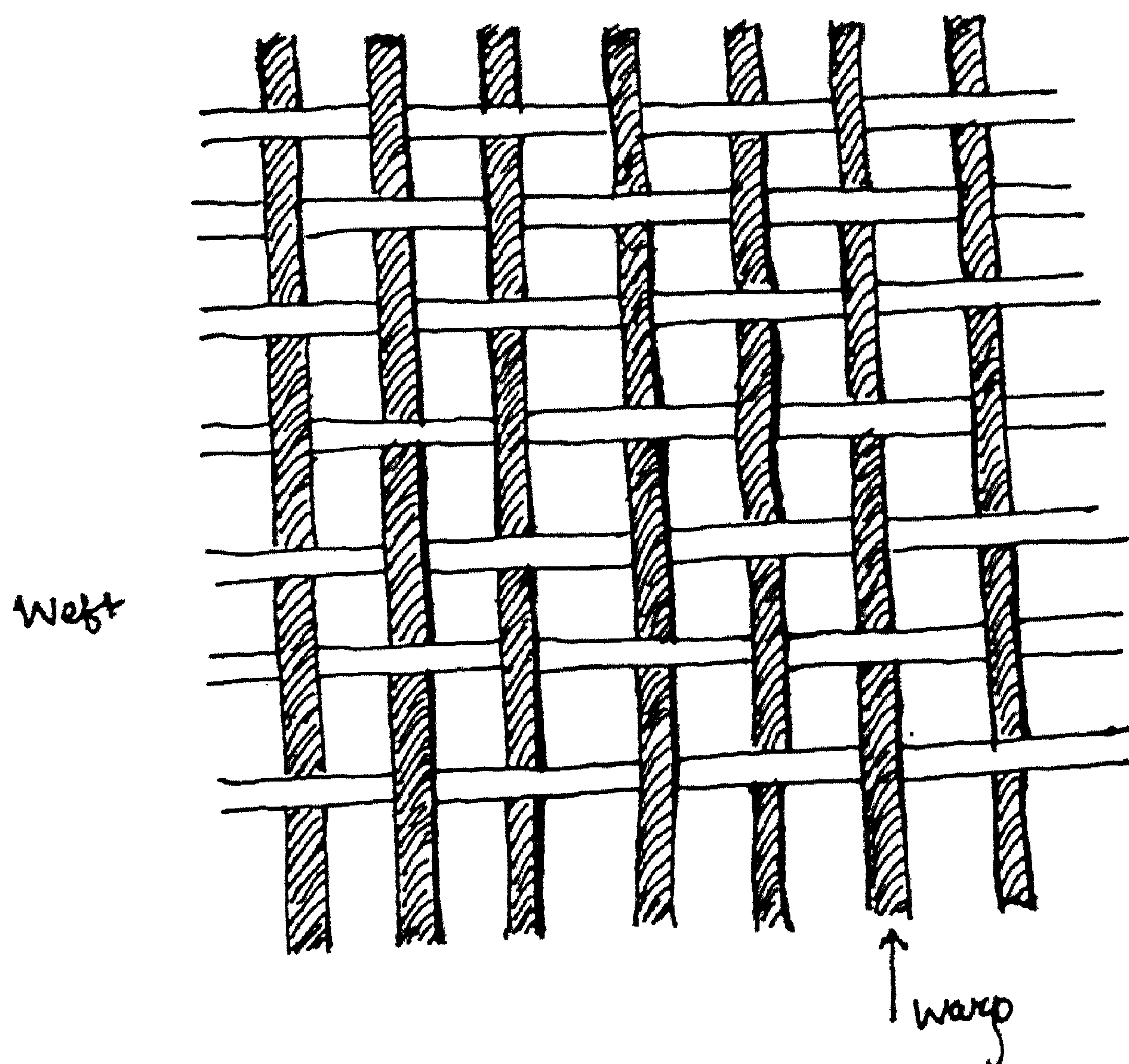


Fig.8. Structure of tabby weave

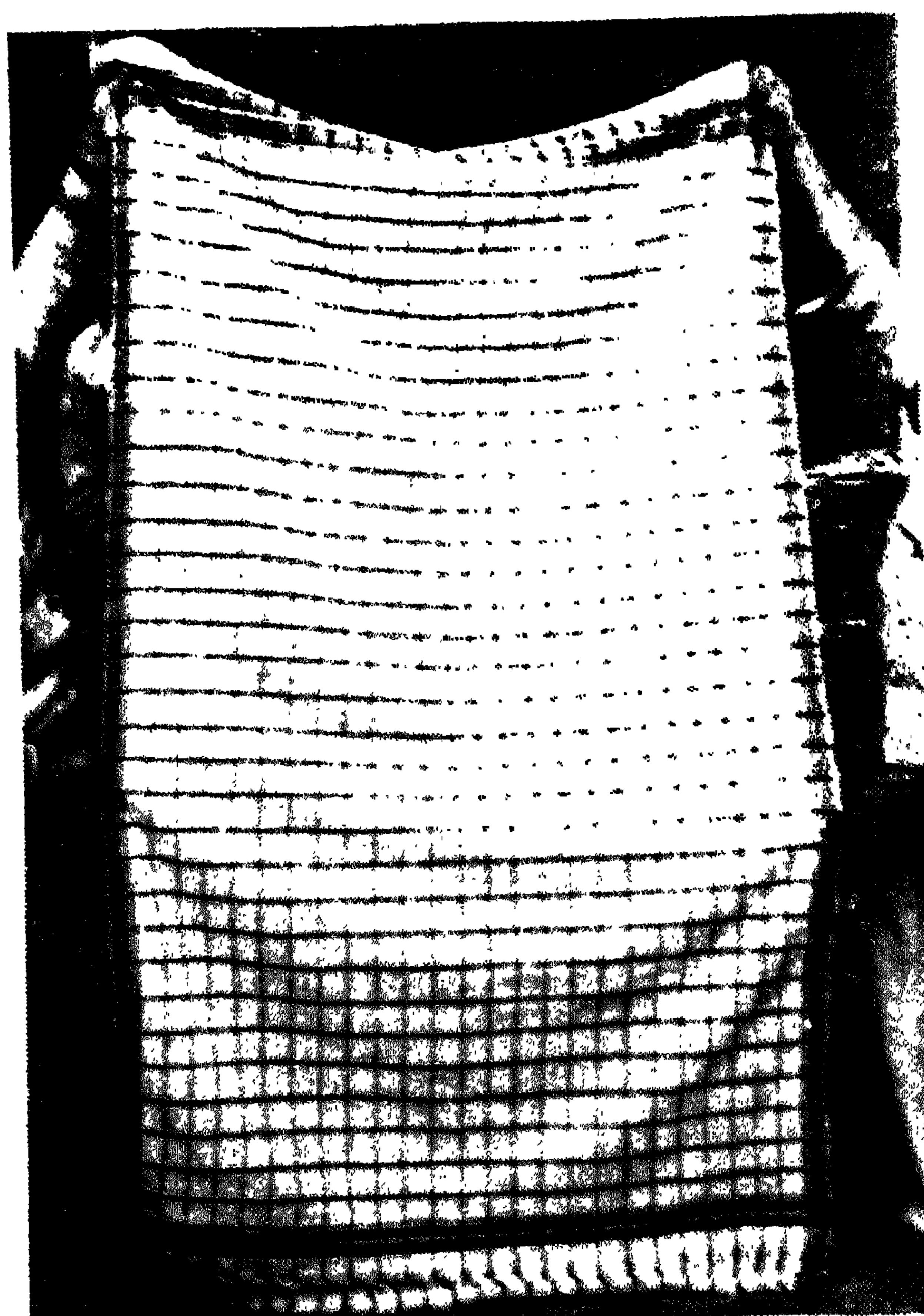


Fig.9a. Sample of khes. Courtesy, Pāṇipat Textiles and Handicrafts Pāṇipat

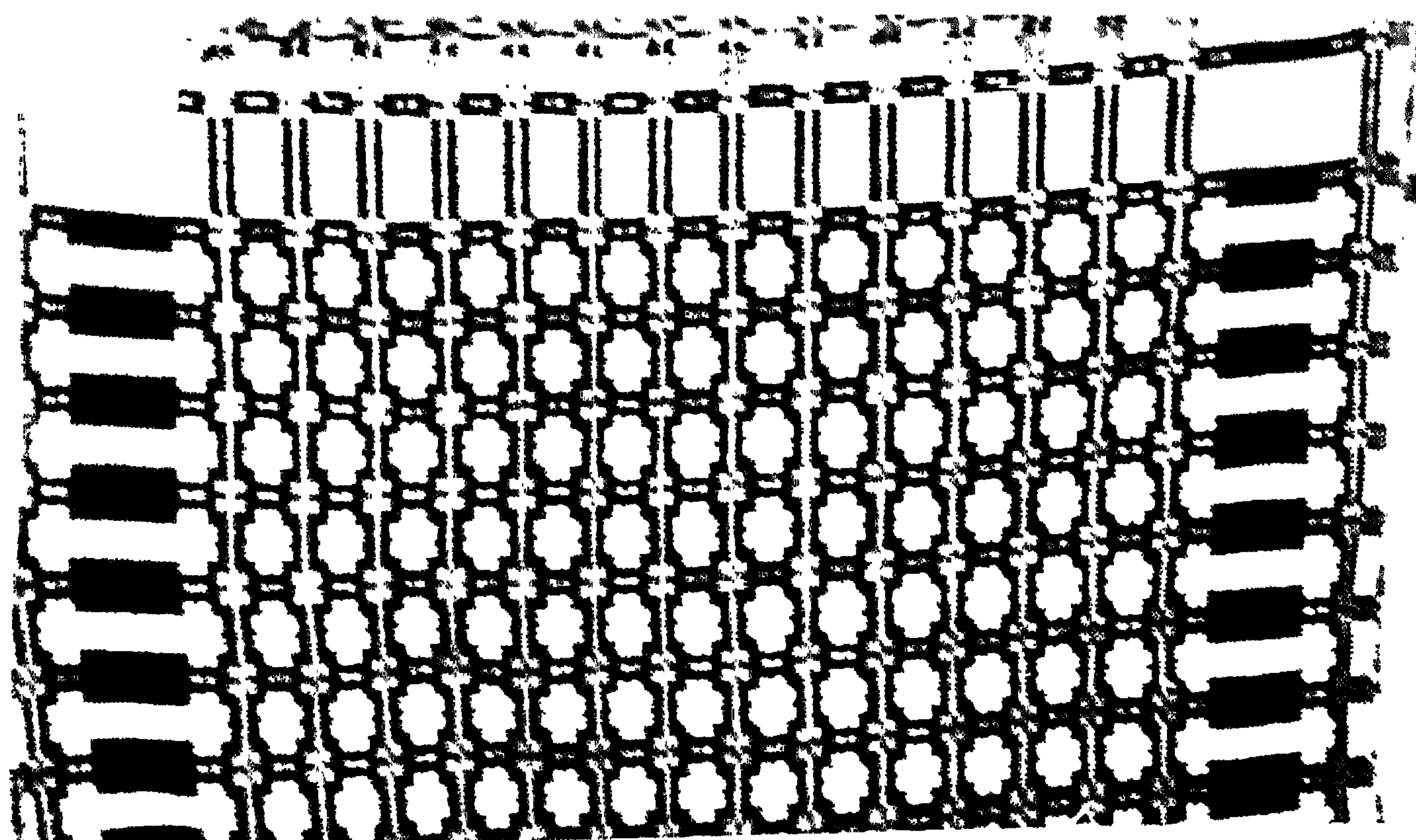


Fig.9b. Samples of majnu. Courtesy, Pānipat Textiles and Handicrafts, Pāṇipat

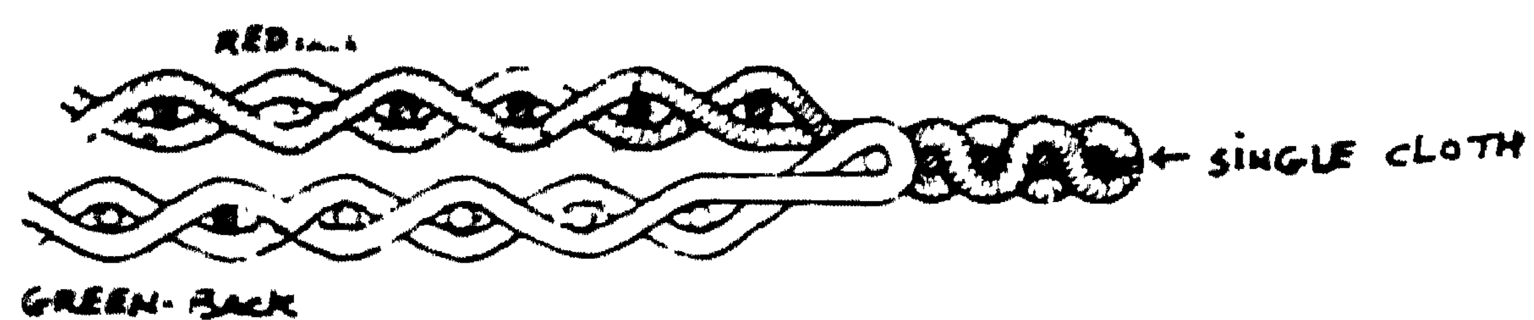


Fig.10. Structure of two faced Pitāmbar



Fig.11a. Multi shaft and peddle loom used for weaving sāri borders



Fig.11b. Shaft and peddle attachments. Note narrow width of border, geometrical mirror image motifs and bobbin used



Fig.11c. Manipulation of peddles with the big toe of each foot. Figures 11a-c were photographed in August, 1981, at the loom operated by Sri Mani Lal Somnath Sakdi at his home/workplace, Serima Jeevan Pole, Ahmedabad

Pashmina, to mention one example; the prime example of dovetail tapestry is the Kulu and Kinnaur body wrapper of Himachal Pradesh (*Fig.19.*).

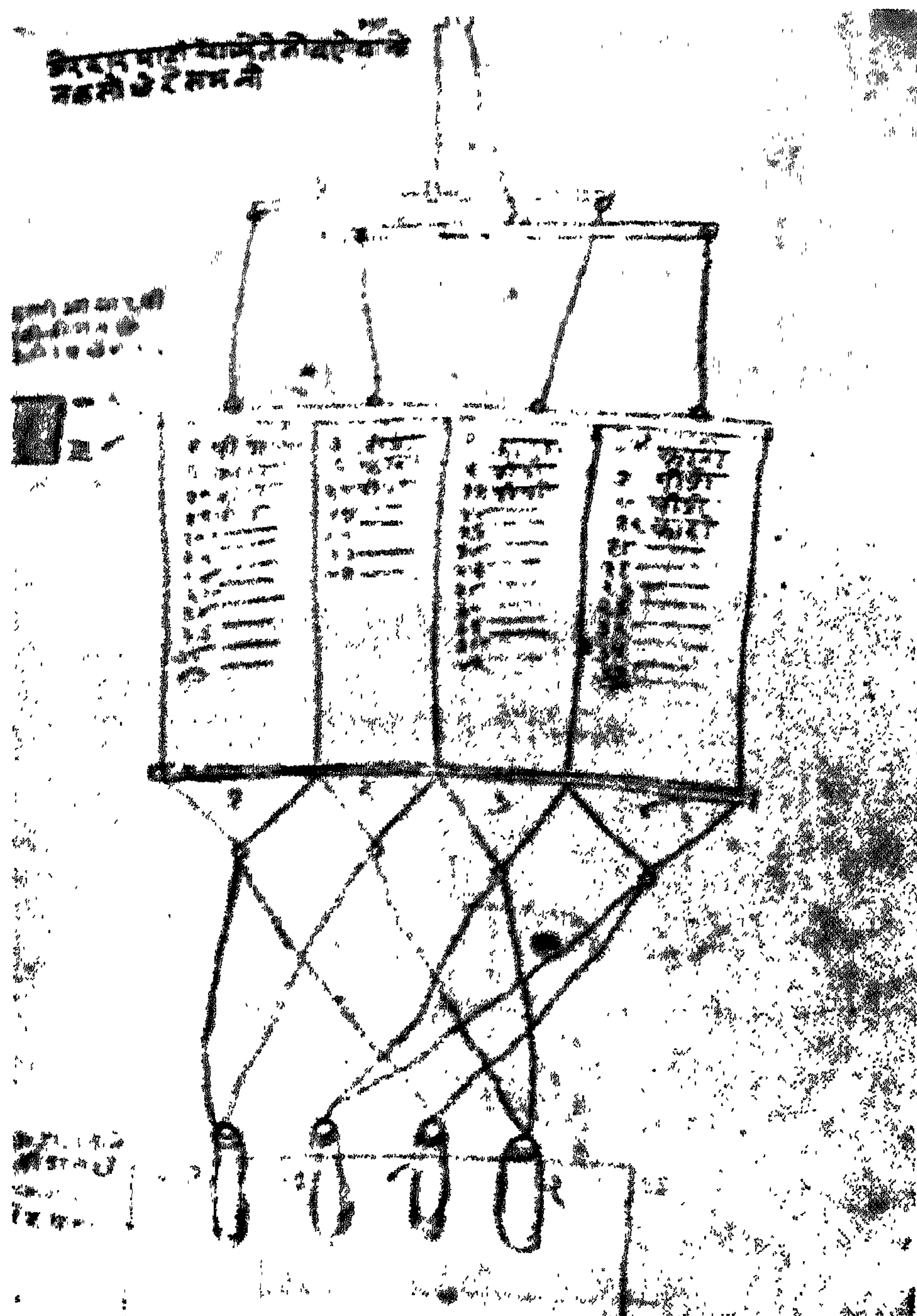


Fig. 12. Newar shaft loom. From sample Book dated circa A.D. 1880 Courtesy, Kutch Museum, Bhuj

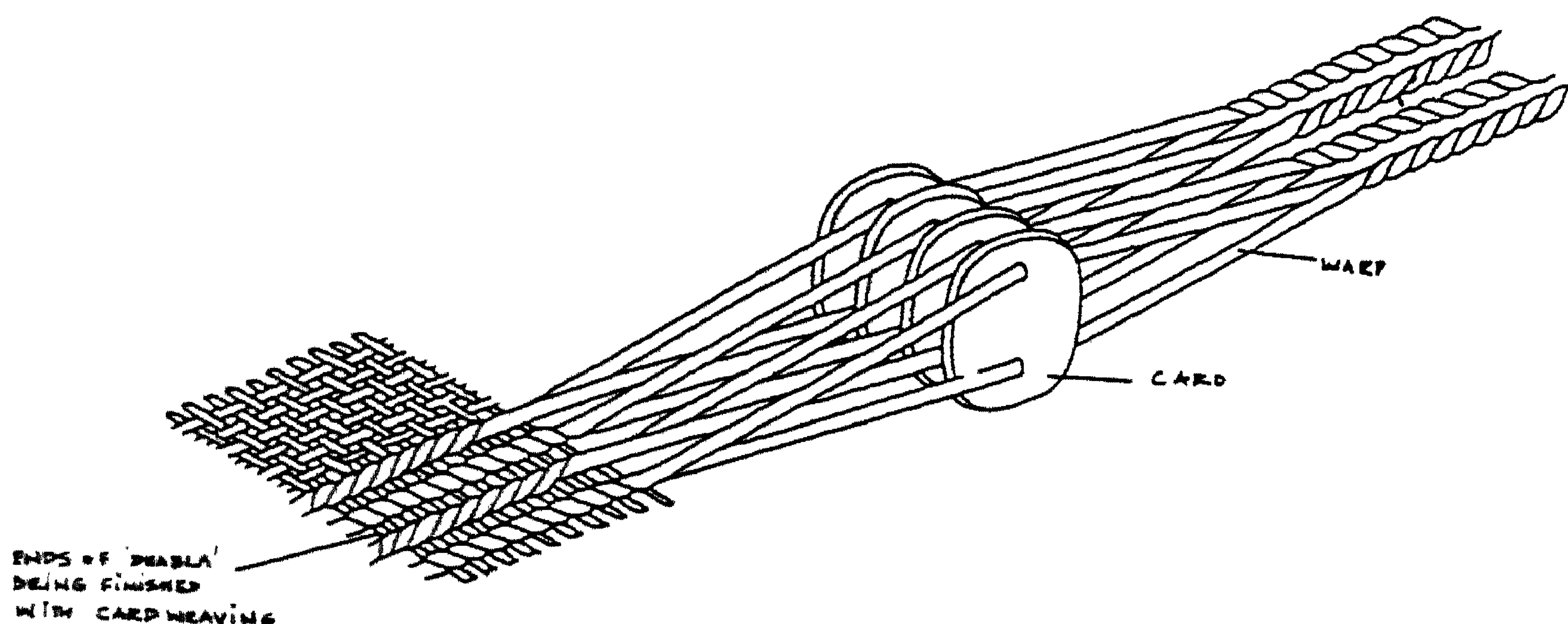


Fig.13. Tablet weaving apparatus

In South India where garments follow the mode of the ground fabric being fashioned in one colour with borders of another, the interlock is found at junctions where two opposing weft coloured picks are united. Since three separate shuttles are used in this category of weaving, this is also called the three shuttle technique (*Fig.20*).

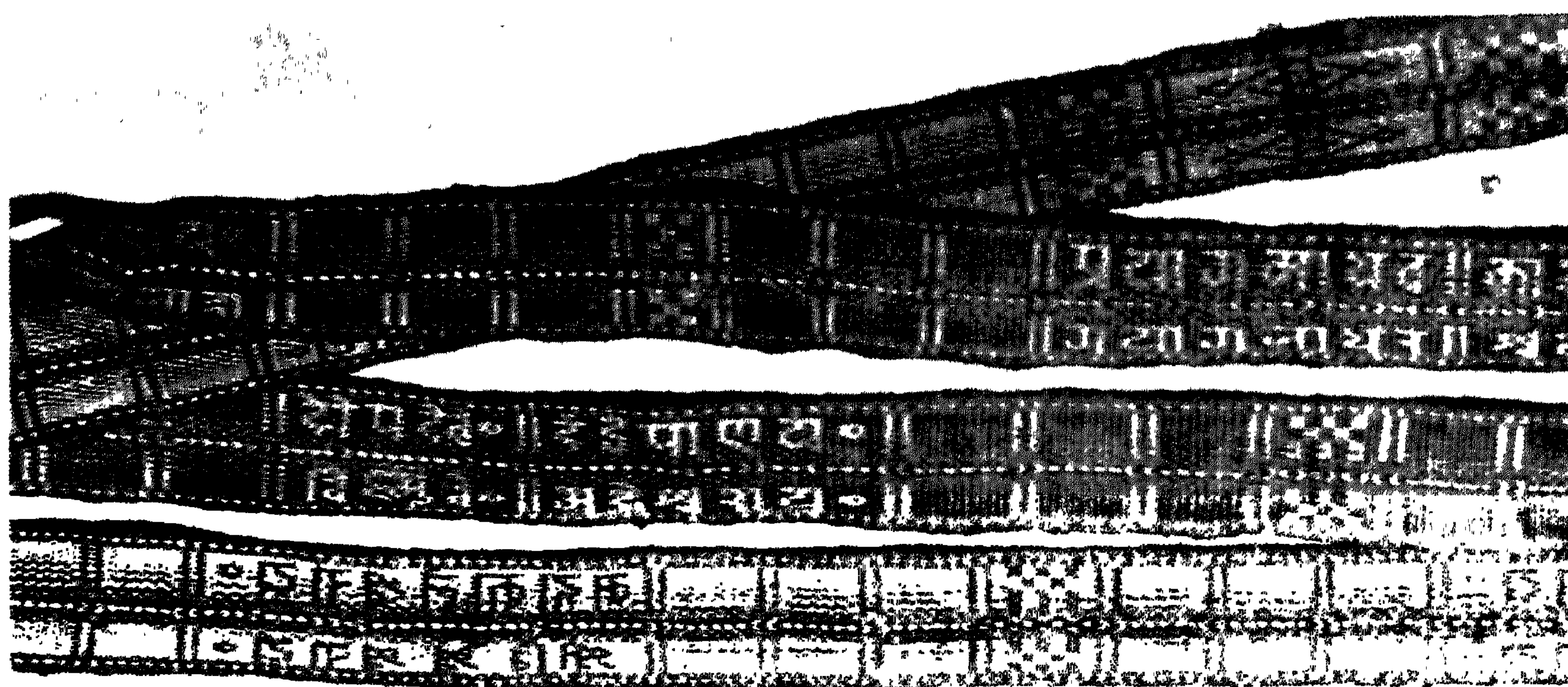


Fig.14. Tapes for tyeing manuscripts, possibly made in Varanasi, acquired in A.D.1885. It is double faced in reversible colour. Courtesy, Museum of Ethnography, Department of Southeast Asia, Berlin

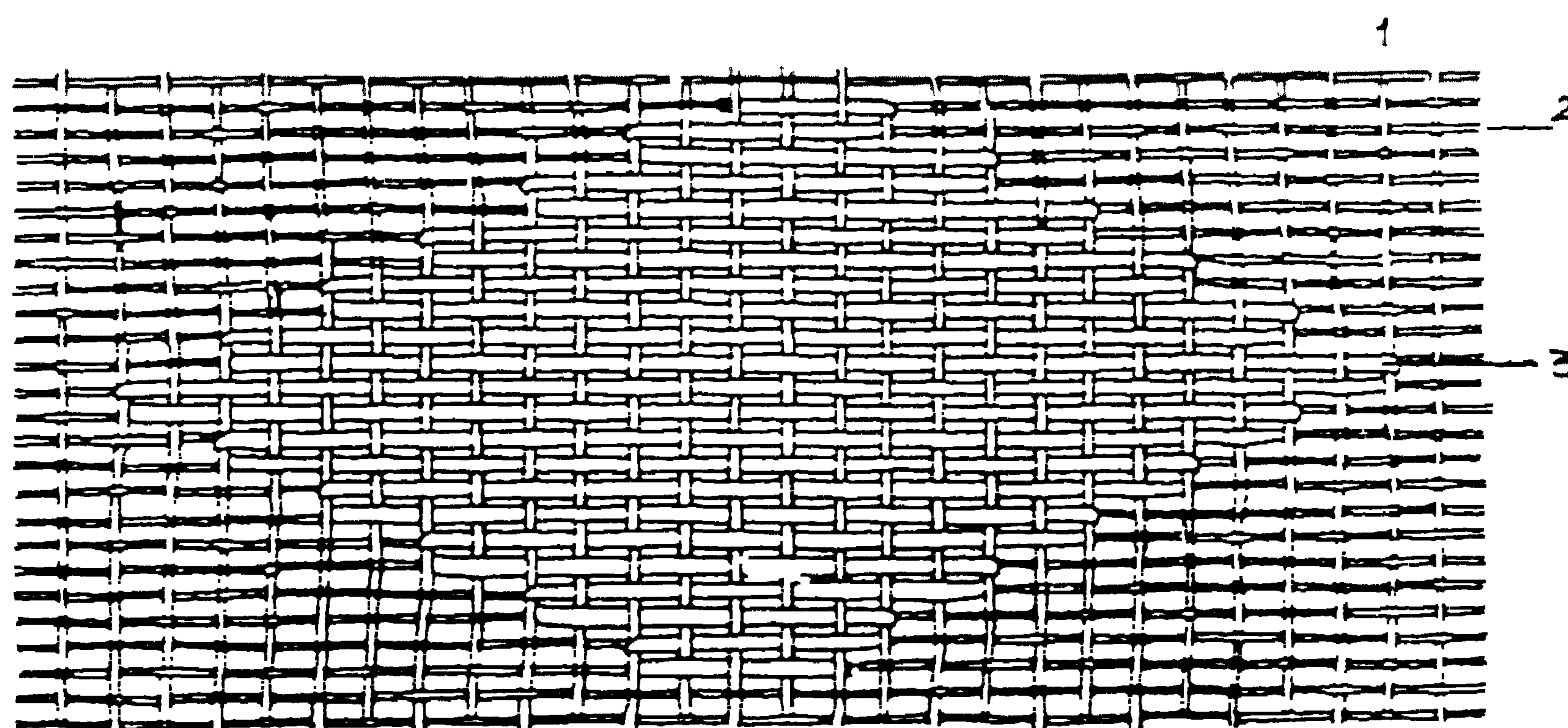


Fig.15a. Structure of Jāmdāni fabric. (1. Warp, 2. Weft, 3. Supplementary weft)

The major differentiation between the North and South Indian schema in ornamentation is that in the former there is greater reliance on weft patterning whereas in the latter there has been a greater orientation to warp ornamentation. This is reflected in loom typology. The ability to experiment with weft structures is associated with the development of the reed which ensures a more even separation of ends and maintenance of tension. The reed number is related to the count of the yarn, and this in turn, conforms to the structure of the fabric. Its presence on the loom would also facilitate the working of loom attachments such as multiple shafts and harnesses.

The level at which major innovations to the loom begin to taper off is marked at the point when the harness attachment, associated with the drawloom, comes into existence. Functionally, the mechanism of the North, simplistically called the

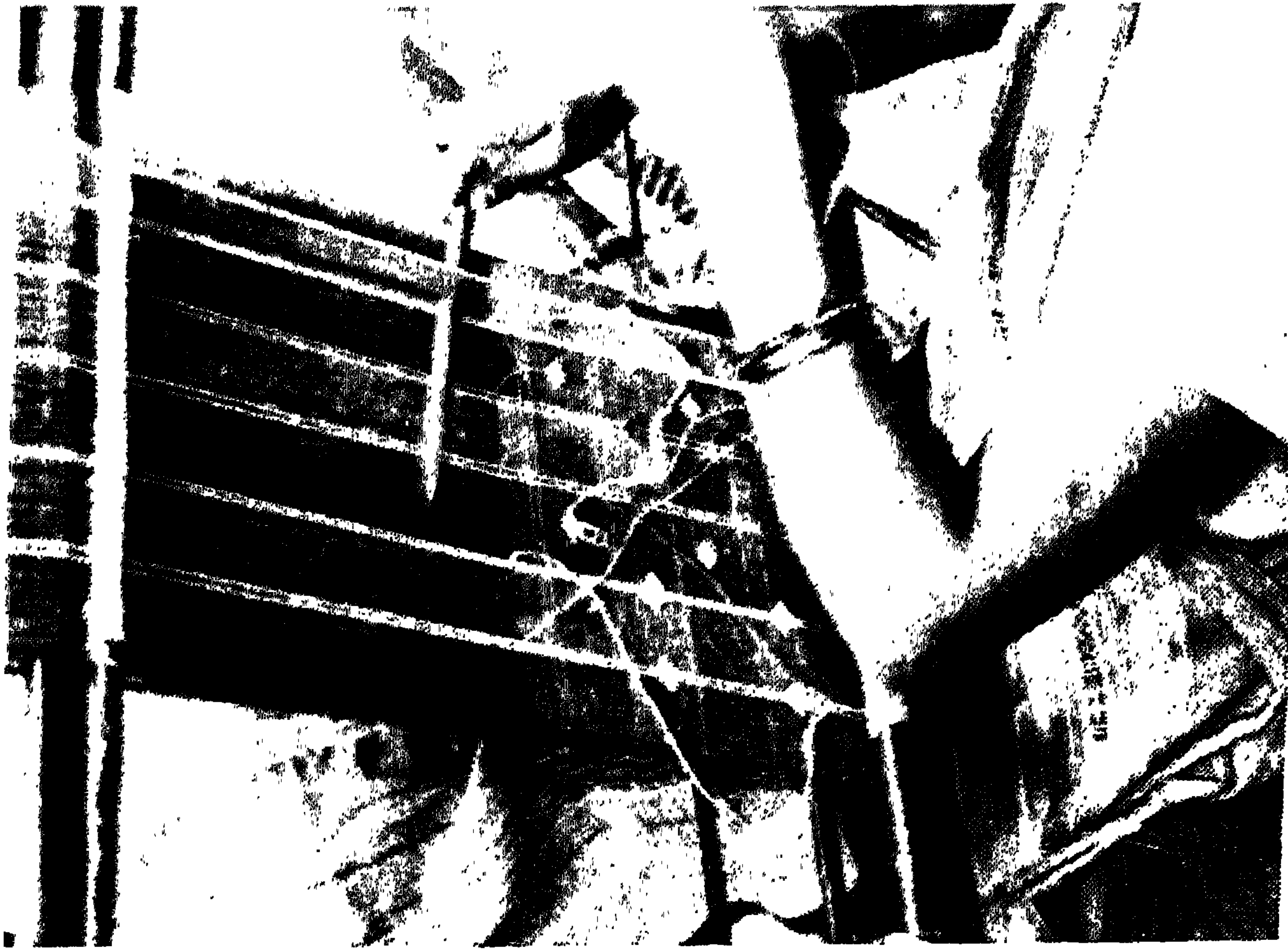


Fig.15b. Lifting of warp ends for design area in Moirangphee fabric done through the Jamdani technique. Srimath Lungham Chothe, Chandel, Manipur, Photographed at Craft Museum, New Delhi, 1990

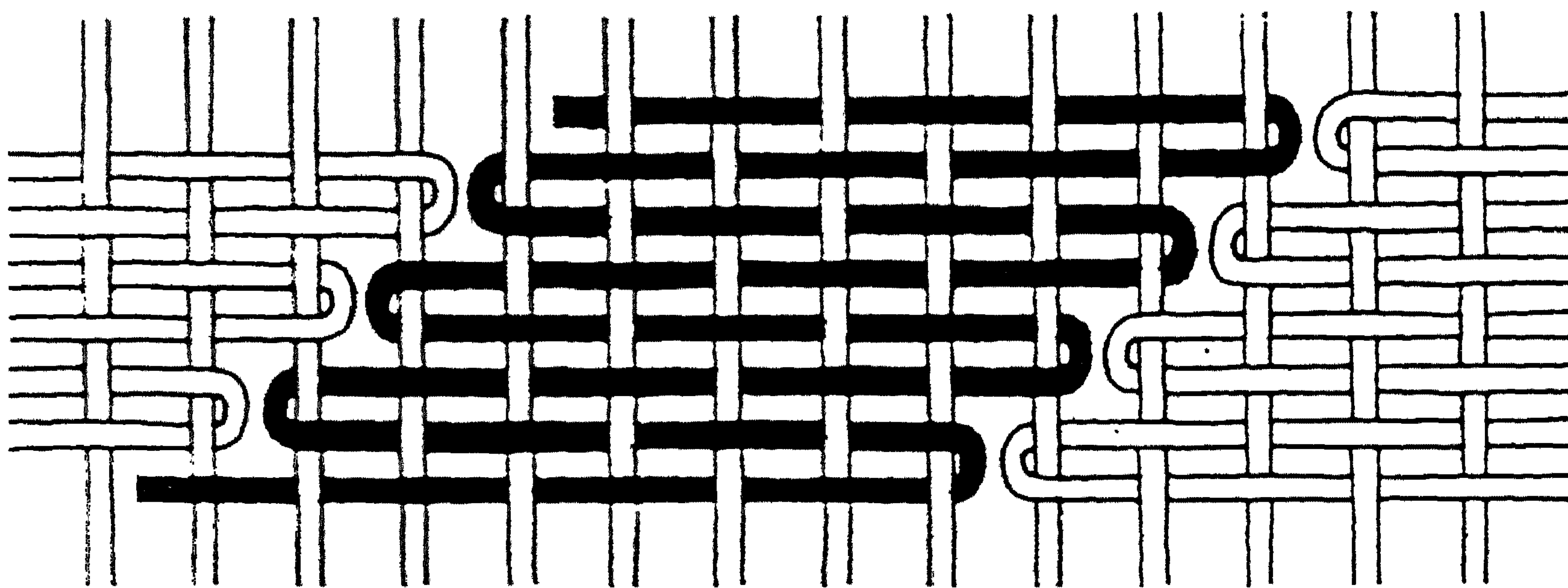


Fig.16a. Structure of slit tapestry as in pānjā dari

Banaras *jala*, and that of the South identified through the terms, *jhungu* and *adai*, are similar.

However, there is a wide disparity if these are viewed from the points of view of origin and chronology. The Banaras *jāla* is derived from the Persian drawloom which achieved its specific identity under the Seljuks, A.D. 1038-1194 (Wulff, p.176; Varadarajan, 1991, pp. 208, 217, 4.5). This would place the Banaras jala

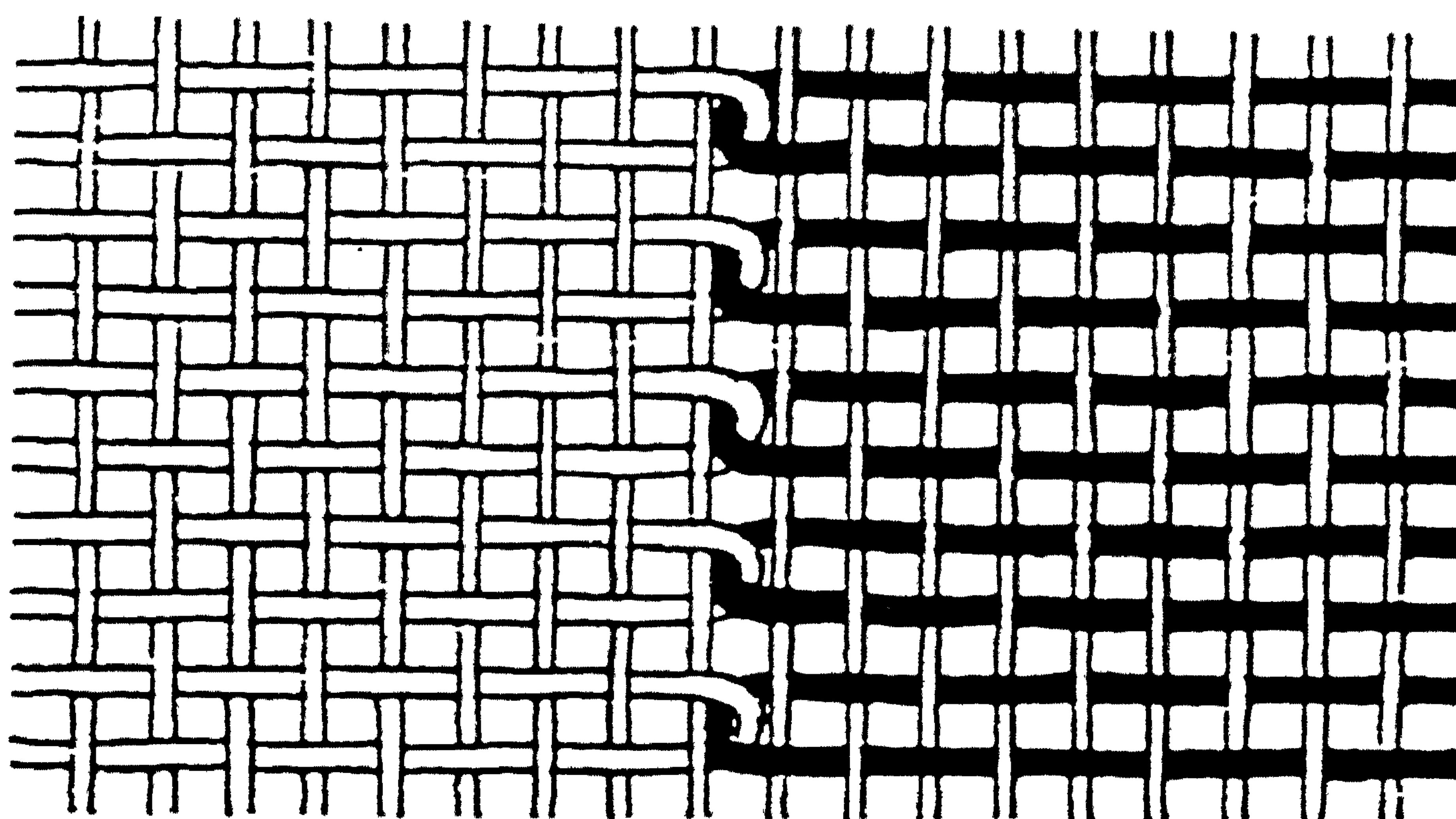


Fig.16b. Structure of single weft interlock found, on occasion, in Kāni Pashminā

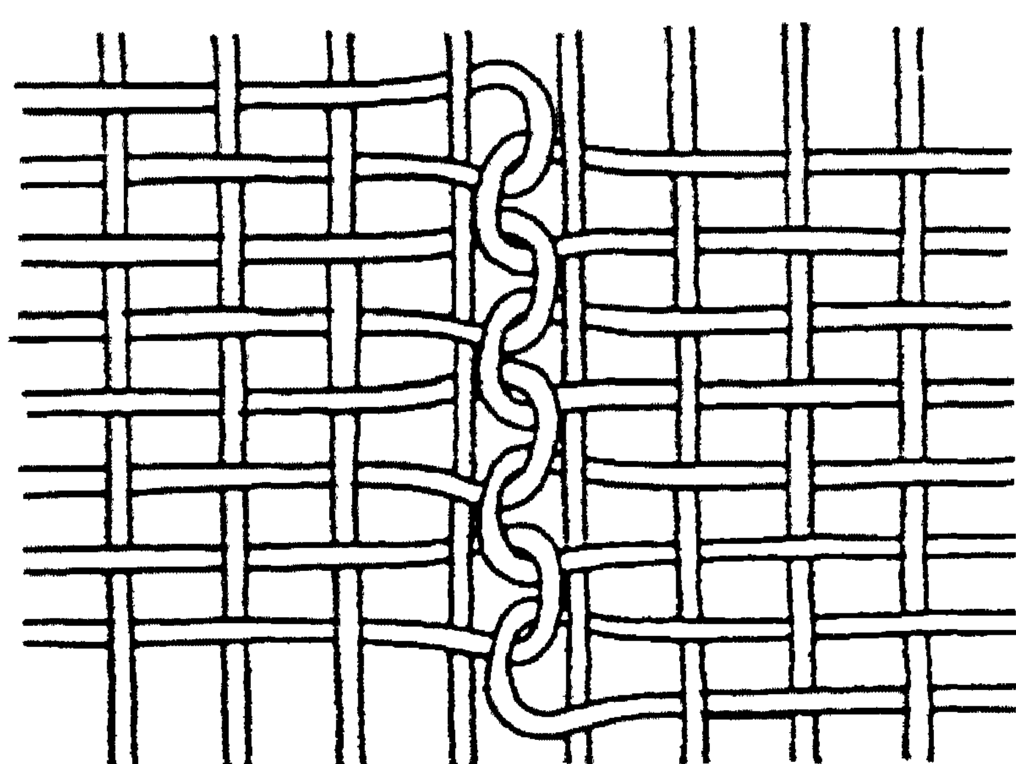


Fig. 16c. Structure of double interlock found in Kāni paśminā and Paithāni borders an Pallus

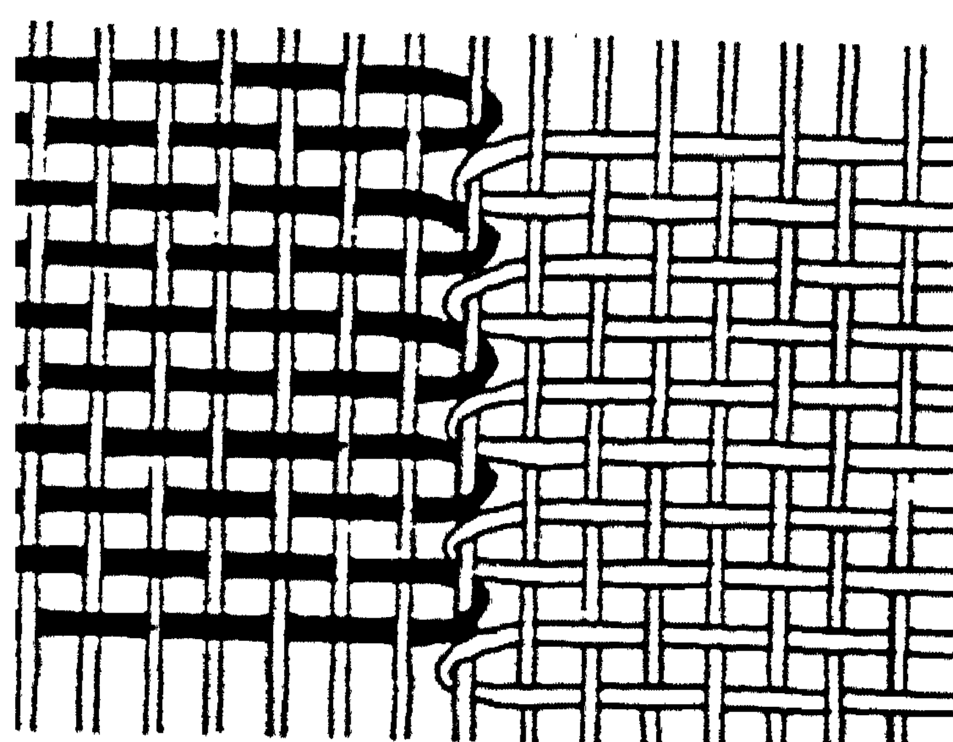


Fig.16d. Structure of dovetailing. This is found in Panja dari weaves and border ornamentation of Kulu and Kinnaur weaves, Himachal Pradesh

well within the medieval period. The lineage of the *ādāi* and *jhuṅgu* (*Fig.21*) on the other hand, can be traced to the Malay Kota Bahru and the Chinese Han dynasty derived Kuala Trengganu loom of Thailand [28]. In *ādāi*, the weaver manipulates the extra warp ends by pulling *jhuṅgu*, tassels attached to these ends above the loom (*Fig.22a.*). For elaborate weft ornamentation a helper standing to the side of the loom operates the harness (*Fig.22 b*).



Fig. 17a. Sample of double interlock on Paithani pallu. Reverse side. Note verticle ridges at colour junctions where double interlocking has taken place



Fig. 17b. Sample of double interlock in Kāni Paśminā. Reverse side



Fig.18. Pañjā Dari. Courtesy, Pāṇipat textiles and Handicrafts, Pāṇipat. The actual slit is prevented as color junctions follow a stepped outline



Fig.19. Loom of Srimati Gyan Bhagati, Thapasari village, Kinnaur. The red weft is passed manually under lifted ends. Note jagged outlines of white motif where dovetailing with orange weft has taken place on the vertical plane

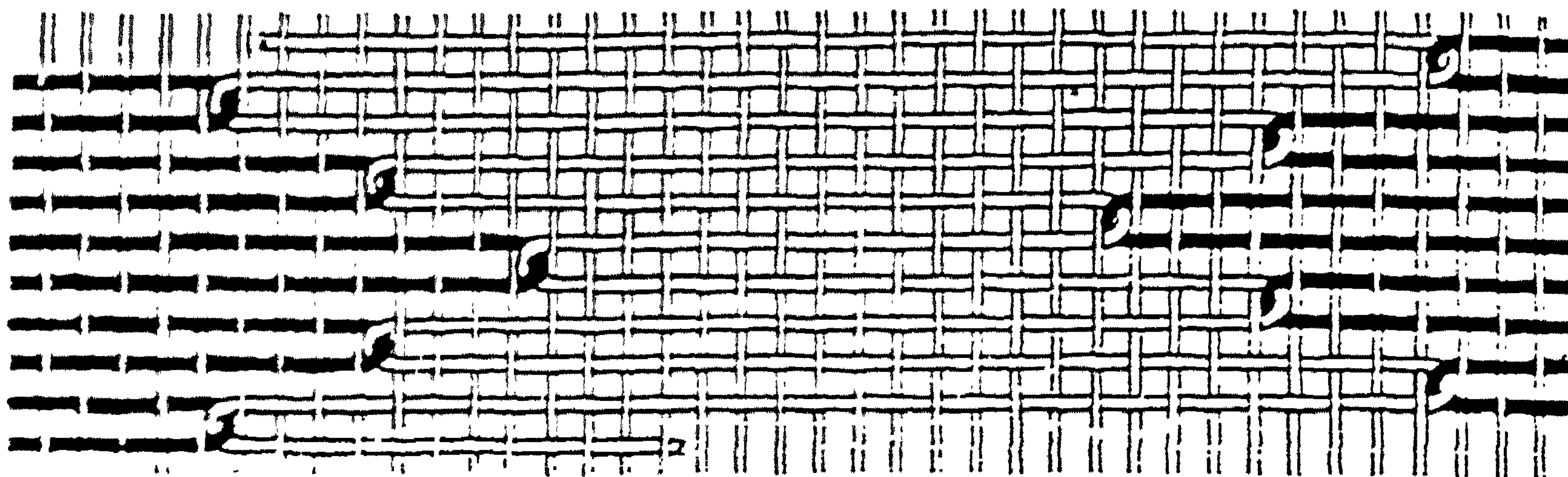


Fig.20. Structure of three shuttle weaving

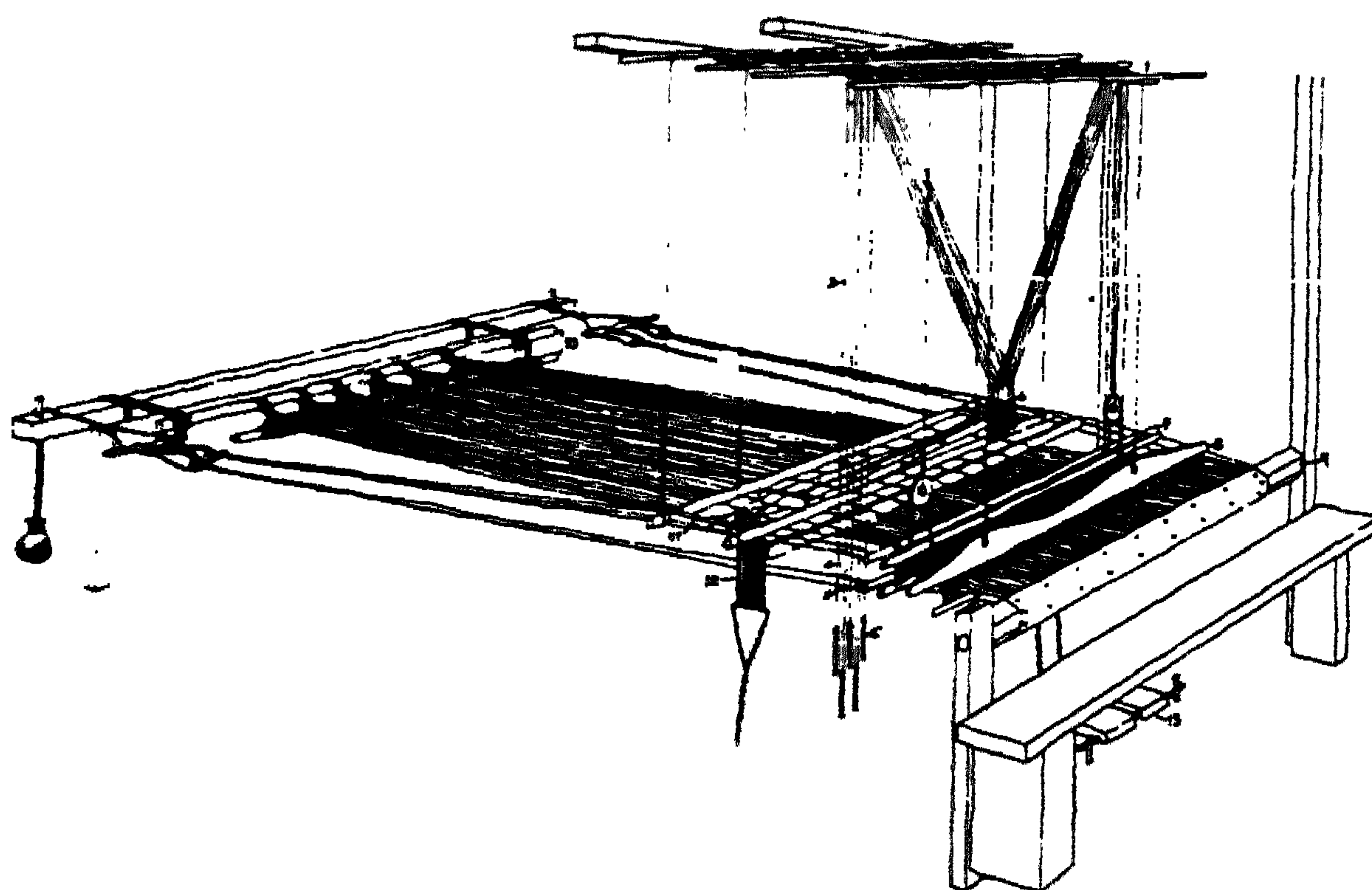


Fig.21. The Ādāi Loom. 01. Comber Board, 02. Harness, 03. Maileyers, 04, Varnish Healds, 05. Lingo, 06. Jungus, 07. Shafts, 08. Reed, 09. Cloth beam, 10. Warp beam, 11. Cross threads, 12. Cross border Jungus, 13. Pedals

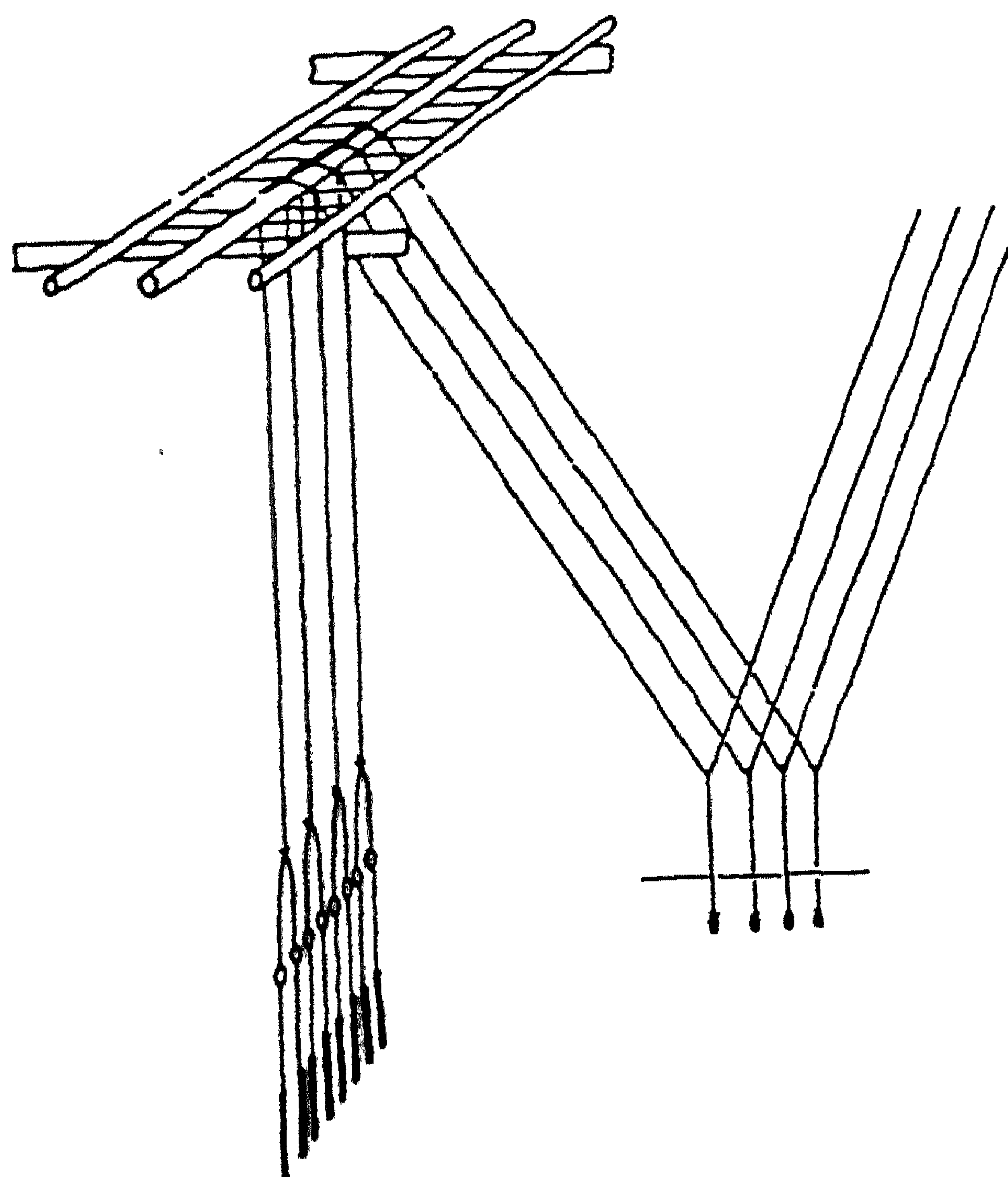


Fig.21a. Part detail of Harness for Ādāi for extra warp

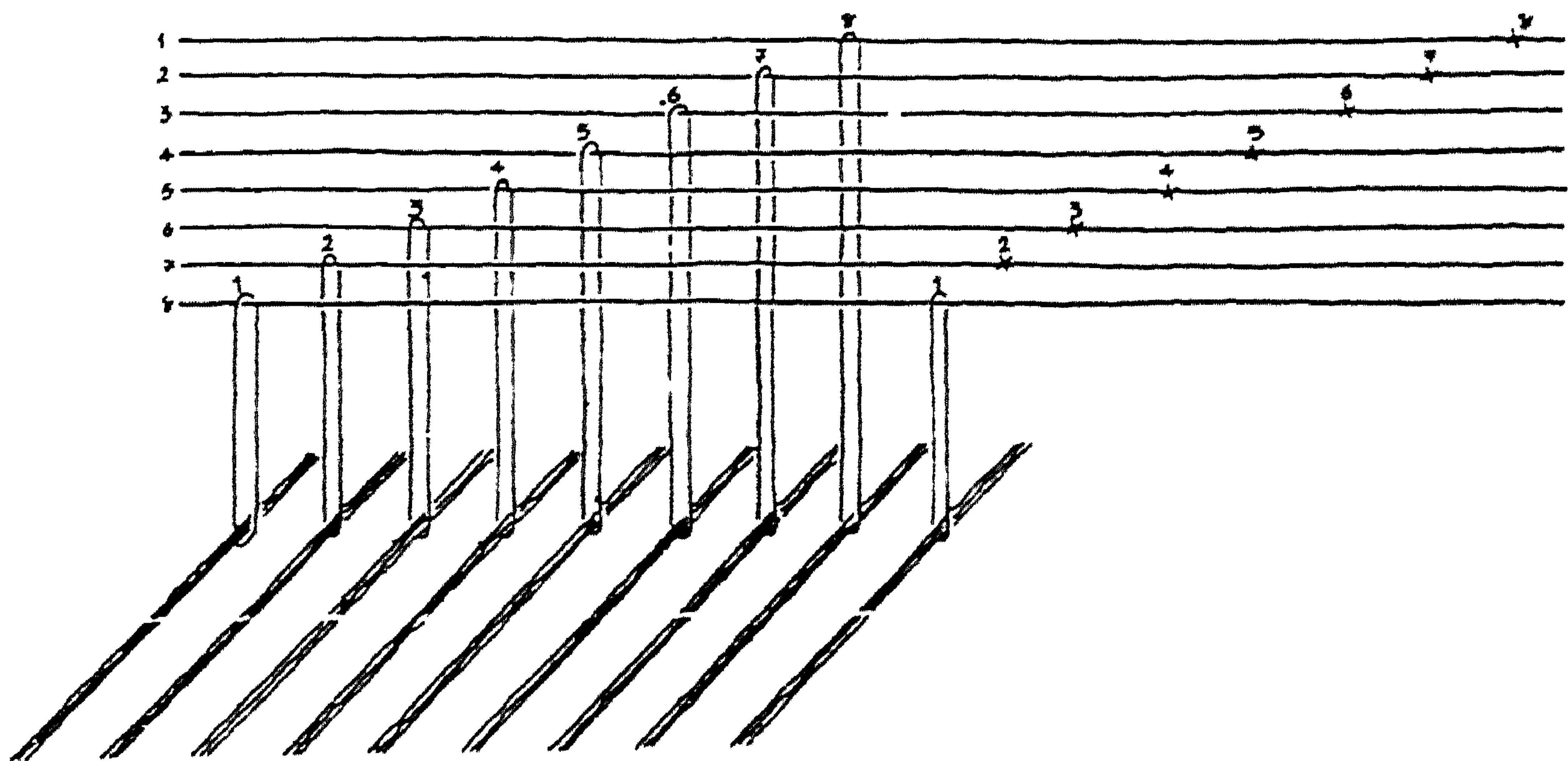


Fig.21b. Cross border pattern healds (vaḍi) tie-up order



Fig.22a. Weaver manipulating Jhuṅgu for border ornamentation

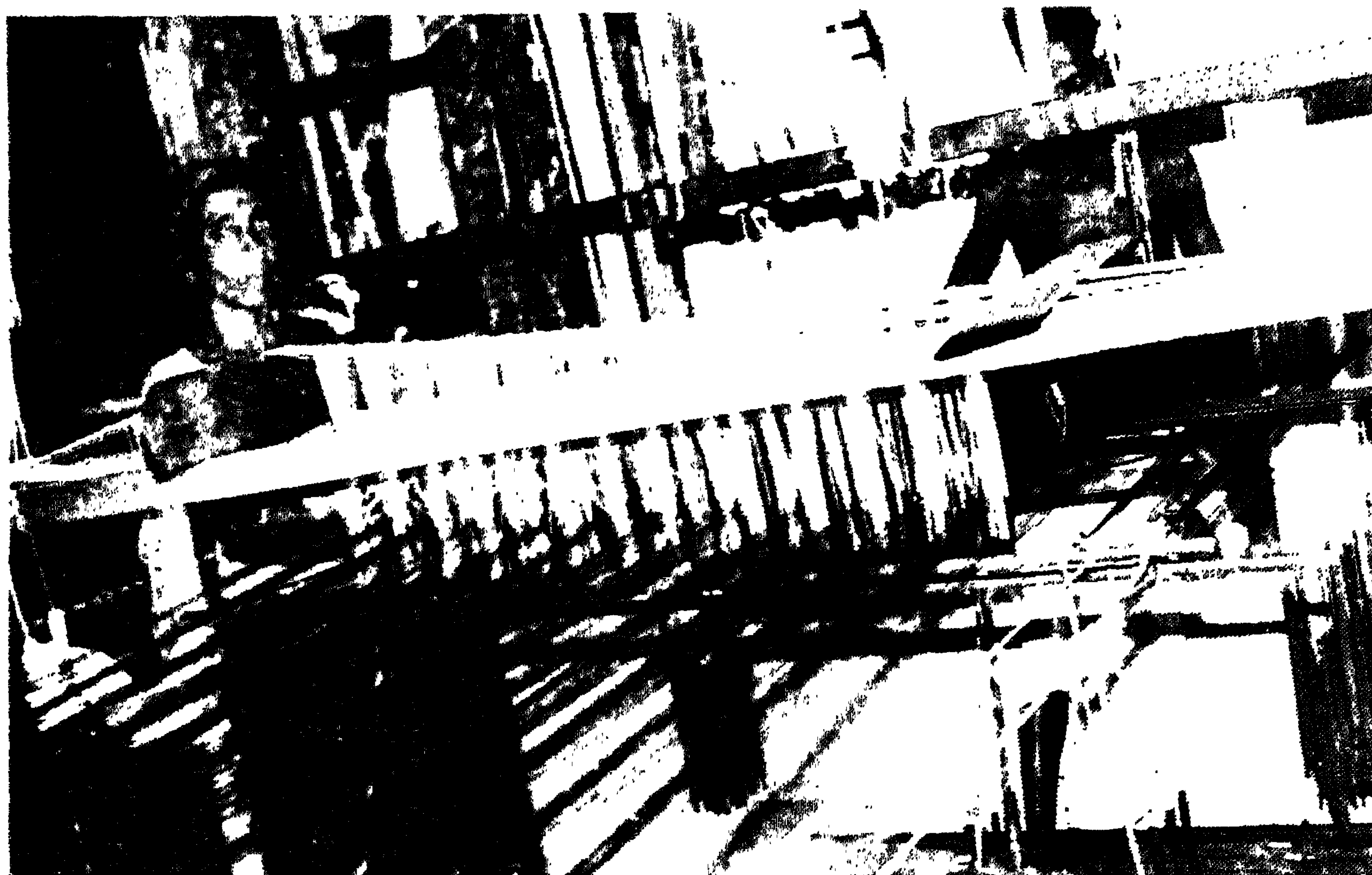


Fig 22b. Woman manipulating ādāi. 22a, b, photographed in June, 1981 at the Kalakṣetra Craft Education Centre, Adyar, Madras

Conclusion

In the absence of archaeological evidence and written records pertaining to textile technology, any attempt to trace the evolution of this technology during the ancient period has to be based on ethnographic evidence and craft tradition. Methodological problems arise which can be traced to the implicit dichotomy between historical evidence for which an established time frame and chronology are of prime importance, and ethnological evidence which cuts through the barrier of time and finds its anchorage in cultural modes. However, there is an innate logic in the latter which facilitates identification of false presumptions, bringing inferences made in this sphere into line with hard historical evidence. It is this methodology which has been adopted in this review aimed at tracing textile technology of the ancient period in India.

Notes

The term textile is derived from Latin, texere, to weave. It refers to woven (i.e. interlaced warp-weft) fabrics The term, fabric, is a generic term for all fibrous constructions (Emery, "The Primary Structures of Fabrics", 1980 p.XVI.) For definition of cloth see Emery, pp.86, 208-210.

Usage of animal skin by ascetics is mentioned in the Ṛgveda. This text is dated by Kane between B.C.4000- 1000. Vedic texts refer to animal skins as ajina Macdonell, and Keith, p.14, ajina, q.v. The bark cloth tradition which is so

rich in Africa and the Pacific Islands, is relatively weak in India. Valkala, a bark cloth worn by ascetics, is mentioned in the Yājñavalkya-smṛti and the Mahābhārata (Monier Williams, p.928 Valkala q.v.; Sardesai and Padhya, p.61). The Yājñavalkyasmṛti and Mahābhārata have been dated respectively between A.D. 100-300 (Kane,) and between B.C. 4th century to A.D.4th century (Winternitz, p.465, Krishnamoorthy, p.272). Both these texts refer to a bark cloth, potti in usage in the districts of Ganjam in Orissa and Vishakhapatnam in Andhra Pradesh. It is not clear if this has been confused with the woven bast fibre, pāṭa, which, according to Professor R.S. Singh (formerly of the Department of Rasa Shastra, Institute Medical Sciences, Banaras Hindu University, Varanasi), is derived from a plant of the Maḷvaceae family, the fabric being called Pāṭu (see below paṭṭa n.10).

At a much later date, the Garo tribe of Northeast India receive notice for Phakram, Grewia (Leea) liliaefolia; Thewek, like Phakram, a leguminous tree; Phrap, a Ficus, and Chram, an Artocarpus jack fruit. See Walker, pp.15- 16. Mittre on p.46 notes that in South India bark of Antiaris toxicara is soaked and beaten into cloth.

3. *Namda, felt, is made from sheep wool in Kutch Gujarat, Tonk, Rajasthan and in Kashmir. The wool fibre is spread on some material which serves as a mat. The wool is moistened, rolled and pounded until the fibres adhere to each other and mesh into a fabric. Irene Emery ascribes its origins to the nomadic peoples of Central Asia. (Emery 1980, p.22). Wuff(p.222) identifies a date as early as B.C. 2300 to felt in Chinese sources). On the basis of the documentation of felt making described by Louis D. Levine (pp.203-211) at the Kurdish village, Seh Gabi, and equivalent field data available in India, it is clear that the same techniques are followed at Indian centres. Emery (1980) distinguishes between felt and felting as a finishing process in woven cloth. In the latter, woven woollen cloth in subjected to the same process as for felt, and the resulting fabric may present a similar surface appearance. Such a process should, however, be called fulling (Emery 1980, p. 23). India also has a tradition of felting. According to Sri Gangalal Weaver, Chitkul Village, Kinnaur, Himachal Pradesh, after completion of weaving of local woollen material it is soaked in a large container. It is then foot pounded for one day in the same waterfilled container. After drying it is ready for use. Kharcha cloth woven in narrow width from inferior quality shawl goat underfur is fulled in the same way. Kharcha has a multiplicity of uses and is reputed to be waterproof.*

4. *It is possible that Linum usitatissimum was introduced from Ferghana into China. However, in China as in India, It was only grown for oil, (Laufer, pp.293-294).*

5. *Sandesara and Mehta p.27. The Maitrāyaṇī Saṃhitā and Taittirīya Saṃhitā are dated respectively to circa B.C.4000 (Kane), and B.C. 1600. (Satya Prakash, and Sharma, p.5).*

6. *Mesopotamia had developed its expertise in wool, Egypt had traditionally been the centre for linen weaving. The decline of flax as an agricultural crop in Egypt is traced to the 12th century, A.D. Syria, 1935 Wiet, p. 279; Forbes, p.160; Frantz-Murphy, pp.245, 297.*

7. *The Śatapatha Brāhmaṇa, dated to between B.C. 4000-1000 (Kane, V), mentions hemp as śaṇa.*

8. *It is of interest that in Bengal and Orissa, there is living memory of a cheaper variant of the silken ritual garment, called paṭṭa vastra. These are said to have been woven of a mixture of silk and hemp, or of hemp alone. In Maharashtra a similar garment exists, referred to as mugaṭa. In present times, with the help of modern technology, rayon paṭṭa vastra are being fashioned.*

9. *The Bonds and the Gadaba are associated with the Korapat District and the Dudma Falls respectively in Orissa. Samples of Keranga cloth are displayed in the Department of Anthropology, Utkal University, Bhubaneshwar. The loom is a simple frame loom.*

10. *A degree of confusion has emerged resulting from a common terminology, pat/patta/putta for silk as well as jute, Singh, B.N., has demonstrated that patta can be taken as a reference to a cloth woven from a variety of bast fibres. Initially it was derived from plants of the Malvaceae, shifting later to the Hibiscus cannibinus grouping. However, after the 4th century A.D. the term patta was also imbued with the connotation of silk (Gulati p.3). It is possible that the Bengali term pāṭ for jute was coined because of the glossy appearance of the fibre.*

11. *Royle notes that in Bengal Hindus were engaged in the manufacture of jute while Muslims turned to cotton, pp.248-249.*

12. *The manufacture of rope from coir was restricted in earlier times to Kerala and the Lakshadweep Islands. Bast fibres served the same purpose elsewhere. However, bast fibre cordage could not substitute for coir when it come to the equipment of ships tackle in earlier times.*

13. *Schou-me is equated with China grass. Royle describes this as Urtica nivea. Hamilton and Robinson concur with Royle and define its usage as exclusive to that of rope making. According to W. Robinson, it was another species of Urtica called ban khua in local parlance, which was used in weaving, Royle, p.241; Robinson, p.67; Hamilton, p.59.*

14. *Master, Streynsham (p.136. Temple p.339) equates herba/erba with tasar, a wild silk. For écorce d'arbre* **see** *Savary II, p.239, ecorce d'arbre, q.v.*

15. *Satya Prakash, R.S. Sharma, p.5, date the Pāṇini sūtras to B.C. 500. For further references to wool see Ray, pp.208-210; Singh, and Ahivasi, pp. 1-7. Sangam classics such as the Silappadikaram contain references to usage of rats' hair in wool fabrication in the south but such production must have been of marginal importance. See Dikshitar, p.54.*

16. *Wilson, pp.168-178; Gazeteer of Kashmir and Ladak reprint 1974, pp. 69-74; Khan, p.232; Khushi Mohammad, p.181; Barker p.318; Carroll, pp.25-26.*

17. *With regard to the antiquity of the tapestry weave it is of interest to note that the earliest Egyptian tapestry was excavated from the tomb of Thotmes IV, B.C. 1405. Broudy, p.44. The tradition in Egypt is that of slit tapestry.*

18. *For silk in Arthaśāstra see Kangle.II pp.104-105, 2.11 102-124.Prof.B.N.Mukherjee (Oral communication,30 Dec, 1981, Dept. of*

Ancient Indian History, Calcutta, dates Arthaśāstra to a point earlier than first century A.D.

19. *For further details refer to Yusuf Ali, pp. 1-8. The distinction between domesticated and will silk is based on whether the worm can be reared under controlled conditions or not, i.e. whether the worm is fed indoors or left to find its nutriment and complete its life cycle outdoors.*
20. *Candolle, pp. 403-405. For the find of madder dyed cotton fibre in Mohenjodaro circa second millenium B.C. see Gulati, Turner, pp.1,4,9; Watson, pp. 356-357, 359- 360, n.7, 363-364.*
21. *For further development of the argument see Varadarajan 1985, p.65; Varadarajan, 1984, p.234.*
22. *For the technology of cotton dyeing see Varadarajan, 1982, pp. 46-59, 75-89; Varadarajan, 1983, pp.43-65; Varadarajan 1991, pp. 210-213.*
23. *In Egypt textile dyeing is associated with the New Kingdom, B.C. 1570-1085. Funerary inscriptions indicate that red, blue and green were required by the gods and the deceased. However, with the exception of indigo, expertise in dye technology for linen was difficult to attain and dyes were very expensive. Upto the early 6th century A.D., therefore, clothing of the Egyptians in daily life tended to be monochrome. Carroll, p.32; Vogler, pp.162-163.*
24. *For wool and silk dyeing see Muhammad Hadi, pp.35- 41,41-44.*
25. *A variation of block printing restricted to silk guaze was the clamp resist method practiced in Gujarat. See Buhler, and Fischer, pp.3-7.*
26. *Varadarajan and Patel, p.20. The reed not only maintains even spacing and tension but also serves to comb the warp ends in course of weaving.*
27. *The item categorised as khes in Pakistan corresponds to the article in Fig. 9b. In India, however, there appears to have been two categories, khes and majnu. Khes is a rough quality off-white or checked handloom material used as wrapper in Punjab. According to Sri D.N. Vij, Panipat Textile Handicrafts, Pāṇipat, majnu is a double cloth with a patterning as shown in Fig. 9b. The technique was ascribed by him to Multan.*
28. *This problem has been discussed in greater depth in Varadarajan and Patel, pp.8-11.*

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Agriculture

LALLANJI GOPAL

Agriculture has been the main productive activity in India. The practice of agriculture is evidenced from very early times in the neolithic phase. There were attempts at improving the agricultural technique and also collecting and systematising the fund of knowledge. Some socio-religious practices and political measures had also helped to extend the benefits of agricultural technology to newer areas. But, considering the conservative nature of the Indian cultivator and the very long period of time involved, the pace of change can be termed as extremely slow.

We can form some idea of the nature of agricultural technology in ancient India, but it is very difficult to mark out prominent stages in the course of its long history.

Tools, Appliances

The development of agriculture is reflected in the number of tools and implements fashioned by any community and their effectiveness. They help overcome the difficulties presented by nature and geography.

Of the different stages in cultivation the impact of implements is seen in the first and basic one, that is tillage. The nature of operations under the tillage may vary from region to region and so will vary the implements. The resources of the cultivator also go a long way in determining the implements to be used. Hence we cannot expect a chronological uniformity in the development of tools throughout the country.

Digging stick, hoe and spade are the most ancient tillage implements (Singh, pp. 39-46). Digging sticks with weights made of stone are reported from Mehrgarh, Chirand, Langhnaj, Inamgaon, Ahar and Nevasa since neolithic times. Stone hoes are also evidenced at neolithic sites of Mehrgarh, Burzahom, Jatkara (Khajuraho) and Naga and Sadiya hills of Assam, but none made of either bone or wood has been reported so far. Hoe is the most simple, multipurpose tool for any agricultural community. Though we cannot rule out the possibility of hoes being made of copper or bronze in the second millennium B.C., no single specimen has been recovered.

We do not have any archaeological evidence for spade before the fifth century B.C.in Ujjain (*IAR*, 1957-58,p.34, Pl.XXXVIII.8).

The Vedic literature mentions *abhrī* as a digging tool (Roy, pp.130-131). It was hollow and was a span or sometimes a cubit long. It was held by its upper part. Generally it was sharp on one side, but sometimes had sharp edges on both sides of its lower portion. It was used both for levelling the land and for digging holes. Though generally translated as spade, some scholars suggest it to be a mattock and not real spade. Vedic hymns dedicated to *abhrī* testify to the appreciation of its utility.

The *ard* or scratch plough, which is known to have preceded the regular turn-plough in West Asian neolithic levels, is not testified archaeologically in India (Clark, Hutchinson and Sahi)[1].

The agricultural surplus of the Harappans presumes the use of ploughing device. But, in the absence of undoubted specimens[2] scholars have attempted speculations (Vishnu-Mittr and Savithri). S. Longdon (Marshall, Vol.II, p.437, Sing. p.68) hazarded the use of plough as the Sumerian sign for plough appears in the Harappan script. Kosambi (p.71) detects the sign of a harrow or rake on an Indus valley seal.The furrow marks in a pre-Harappan field from Kalibangan (Rajasthan) (c.2900-2700 B.C.) make a case for the Harappans using plough (Lal, p.1; Frankfort, p.303). Sankalia (p.63) and Allchins (p.192) and Gordon (p.71) had suggested that the Harappans[3] used wooden ploughs. All doubts have been set at rest by the clay models of plough recovered in the excavations at Banawali, Haryana (*IAR*, 1983-84, p.26, Pl.21) and Jawaiwala, Bahawalpur, Pakistan, (Weinner)[4]. The absence of actual plough is accounted for by their being made of decaying material and a village site being still unexcavated.

The Vedic terms for a plough are *lāṅgala* and *sīra*. It was made of hard wood like *Khadira* and *Udumbara*[5]. *Sīra* (plough) was attached to *īṣā* (pole) with a *yuga* (yoke) attached at its upper side. It is debated whether the Vedic people themselves introduced plough or borrowed it from the Harappans. The term *lāṅgala* is given a Muṇḍā origin[6], though an Indo-European association has also been suggested (Wojtilla, pp.27-37)

Scholars generally take *lāṅgala* and *sīra* as being synonymous. But Bloch (pp. 411-18) distinguishes between the two - *lāṅgala* being the plough for breaking the ground and *sīra* the sowing plough.

The Ṛgvedic plough is taken to be a simple and light implement made of wood. But the reference to its well smoothed handle and its sharp pointed share (*AV.* III. 17.3; *Vaj.S.* XII.71, *paviravat, susīma* and *tsaru*) suggests that there was an effort to improve it to make it something of which the owner could feel proud (Aiyer,p.14).

The *Ṛgveda* (VI. 91.1) refers to six to twelve oxen being yoked to the plough. In the *Kathakasaṃhitā* (XV.2) the number goes up to twelve or even twenty-four. The *Atharvaveda* also refers to ploughs drawn by six to eight oxen. This would suggest heavy ploughs required for breaking hard soil. A Ṛgvedic passage

(X.9.2,3,5,7) refers to the use of horses for ploughing. The application of horse power[7] would also imply a heavy plough.

Later literature leaves no doubt that animal traction ploughs had come into general use. Pāṇini (IV.4.81) mentions the terms *hālika* and *sairika* as referring to bullocks meant for plough as distinguished from those used for drawing carts or chariots.

There is ample literary evidence to indicate that ploughing had become the most important operation in tilling.The *Cullavagga* (VII.1.2) mentions ploughing as the first farming operation. Pāṇini (III.1.21) refers to the verb *halayati* meaning 'uses the plough'. This is further indicated by the term *lāṅgalagrāha* (one holding the plough) used by Patañjali (on Pāṇini III. 2.9) as referring to a cultivator (*Bṛh.S.* IV.9 - *lāṅgalajīvin*).

It is not possible to determine the date of the beginning of traction ploughs in India. It is suggested that in India ox-drawn plough is not earlier than the first millennium B.C. (Rapson, p.99). But, the Vedic literature amply shows the use of bullocks for dragging the plough. They were to be coaxed gently and not to be treated harshly. A Ṛgvedic passage (VIII.3.8,12) refers to a ploughman as praising and addressing his oxen while drawing his furrows. According to Randhawa (Vol.1. p.298) plough traces were tied to the horns of the bullocks and yokes do not seem to have been used.

The literary sources mention a number of tools used in digging. Besides *khanitra* (Panini III.2.184) and *ākhana* or *akhana* (*Ibid*, III.3.125) we have a special type of hoe called *stambaghna* (*Ibid*, III.3.83) which was used for weeding out the stumps.

We learn from the *Jātaka* stories that after ploughing the clods were broken and the fields were levelled with the help of spade or hoe (*Jātaka* II.59;V.68). The *Amarakośa* (II.9.12) implies that *loṣṭhabhedana* was a separate tool for breaking clods. Possibly it was in the nature of a wooden club.

Archaeological evidence is not forthcoming for any levelling tool, possibly because it was made of wood. Patañjali (on Pāṇini I.4.49) informs that levelling of the field was done by a long wooden log, yoked by two oxen[8].

Harrow used for preparing the seed-bed after ploughing and for covering the seeds after sowing is not much evidenced. A blade-harrow found in the excavations at Sanchi is 21.75 inches long and 3.125 inches wide, with two vertical tangs, one on each end, fixed into the flat wooden back. *Koṭiśa* mentioned by the *Amarakośa* (II.9.12) is taken to be a harrow (Randhwa, Vol.1, p.418). *Biddhaka* is mentioned by the *Kṛṣi-Parāśara* (verse 118) as an implement nine cubits long and having twenty-one spikes. It refers to Indian harrow.

The *Kṛsi-Parāśara* (verse 118) mentions a tool by the name *madika*. It does not provide any details about its form and function. It merely says that it was 14 cubits in length, the present *moi* is of different forms and shapes. Here possibly we have a reference to a wooden log used for levelling the field.

Specimens of ploughs of ancient times have not come down to us in their full form. The perishable nature of wood has been the main reason. Even in the case of the ploughshare corrosion and rusting have reduced the early pieces to mere metallic lumps. It will be interesting to make a comparative study of the size, shape,

and weight of the ploughshares belonging to different periods and different parts of the country. Likewise, there are depictions of plough in terracotta and sculptural art. Though there has been little change in Indian plough in course of centuries, we can easily notice variations which may reflect regional characteristics. But, no such study, especially in correlation with their modern descendants, has been attempted which may have interesting facts to reveal about the development in agricultural technology.

The literary sources help us form an idea of the plough in ancient times. Pāṇini mentions distinctive terms for some parts of a plough : *īṣā* (the long wooden pole), *potra* (the central bent portion III. 2.183), *kuśī* (the ploughshare IV.1.42), *yuga* (yoke), *yotra* or *yoktra* (rope) and *naddhrī* (leathern throngs) (III.2.182). The absence of terms for other parts does not mean that they did not exist in Pāṇini's time. They are equally important constituents of a plough. Possibly distinct terms for them were coined in course of time or else there was no need for recording them in a work of grammar. The *Amarakośa* (II.9.13, 14) gives a consolidated list of terms for some important parts of a plough: *yotra* or *yoktra* (rope), *nirīśa* or *kuṭaka* (the part where ploughshare is attached to the pole), *phāla* or *kṛṣika* (ploughshare), *lāṅgala* or *hala* (plough), *śamyā* or *yugakīlaka* and *īṣā* (pole) (*Wojtilla*, pp.325-38).

The *Kṛṣi-Parāśara* (verses 112-20) gives a very detailed account of the different parts of a plough (Gangopadhyaya):

(1) *Yuga* or the yoke which is ear-shaped (*karṇasamānaka*),

(2) *Aḍḍacalla* or the pins of the yoke where the bullocks are tied which is 12 *aṅgulas* or fingers (=9 inches) long,

(3) *Īṣā* or the pole of the plough, which is 5 cubits long,

(4) *Niryola* or the plough proper, excluding the ploughshare, which is 1½ cubits.

(5) *Śaula* or an extra piece of wood that tightly fixes the *niryola* to the pole and is a cubit (*aratni*) long,

(6) *Niryolapāśikā* or the plate that fixes the ploughshare to the *niryola* and is 12 *aṅgulas* (=9 inches) long,

(7) *Halasthāṇu* or a strong piece of wood fixed to the *niryola* at the end opposite to the one to which the plouhgshare is fixed, and is 2½ cubits long,

(8) *Pañcanī* or goad made of bamboo with iron top and 12½ or 9 *muṣṭis* or fists (= 4½ or 3 feet) long,

(9) *Ābandha* or a rod of iron, which prevents the *niryola* from falling out of the pole, is cylinderical in shape and is 15 *aṅgulas* (=1feet) long,

(10) *Yoktra* or the tie yoke, 4 cubits long,

(11) a rope, 5 cubits long, and

(12) *Phāla* or ploughshare, 1 cubit or 1 cubit and 5 *aṅgulas* (=3-4 inches) long.

The description of the plough and its parts in the *Mānasāra* (V.56-77) is more graphic. The plough proper is to be made of Babul tree, *Acacia catechu*, nimb, pines or plants containing milk sap and blood. It is to be 1, 1¼, or 1½ cubits long and

3, 4, or 5 *mātras* (=*aṅgulas*) wide at the bottom. At the middle of its length it is to be octagonal, half being three-stripped, like a bamboo leaf. At the upper part of its bottom the top end of a bamboo rod is to be pushed in. The rod is to be 3 cubits long with a proportional breadth so that it may be strong. The length of the plough tail is to be 1½ cubits and its width at the bottom 5 *aṅgulas* (=3¾ inches). As an alternative the tail is to be 1¼ or 1 cubit long. The top of the tail ending by the plough-root is to be 2 *aṅgulas* (=1½ inches). The tail is to be 1 to ½ *aṅgulas* thick. Thr root of the tail is to be furnished with a lotus leaf like device. The length of the ploughshare at the forepart of the tail is to be 3, 4, 5 or 6 *aṅgulas* and its height 2 or 3 *aṅgulas* and it is to be furnished with various devices. At the hole an iron nail is to be driven in. The yoke is to be 2½ cubit long. The ploughshare is to be 3, 4, or 5 *aṅgulas* wide at its middle and 2 or 3 *aṅgulas* at its two ends.

The yoke diminishes gradually from the middle towards the forepart and the hinder. There are two holes for yoking oxen, one on each half of the yoke. Half-way between these two holes the plough rod is to be filled in.

The most vital question about the plough is when did the iron ploughshare replace the primitive wooden ones. The use of iron ploughshares presupposes a fair knowledge of iron. Scholars differ on the question of the knowledge of iron in the Vedic literature. The exact metal denoted by the term *ayas* is not certain. In the list of six metals in the *Vājasaneyī Saṃhitā* (XVIII.13) *loha* (red) and *śyāmam* (swarthy) respectively signify copper and iron, and hence *ayas* would stand for bronze. *Ayas* (bronze or copper) was the metal with which the Vedic people were originally familiar; later on, being introduced to iron, they gave it the name *kṛṣṇāyas* or black metal to distinguish it from the red colour of copper or bronze. Archaeological evidence places the introduction of iron around 1000 B.C., but iron implements seem to have come for frequent use from roughly 600 B.C.(Gopal, 1962).

The earliest reference to iron ploughshare is taken to occur in the *Atharvaveda* (III.17.3) wherein *lāṅgala* is described as *pavīravat* (Macdonell and Keith, p.509). Sāyaṇa takes *pavīra* to be sharp-edged like *vajra* and explains it as the lance made of iron (*ayomaya*), fixed at the end of the plough, which tears the land. Pāṇini (IV.1.42) mentions the ploughshare (*kuśī*) as being filled in the *potra* (the central bent portion) and made of iron (*ayovikāra*). The Kokalika-sutta in the *Suttanipāta* refers to a *phāla* being heated and making sound when dipped into water.

The *Mahābhārata* (XII.262.46) and *Manusmṛti* (X.84) describe a plough as consisting of an iron blade driven into a piece of wood (*Kāṣṭham ayomukham*). Vaśiṣṭha (II.35) praises plough as being *Kalyāṇanāsika*, which , according to the commentator, refers to the ploughshare piercing the field deeply. There are some indirect references suggesting metallic ploughshares[9].

We have some evidence to indicate an attempt to improve the quality and refinement of ploughs. Panini (V. 4.121) mentions terms for a farmer having a good plough or a bad plough. The advantage of using a large plough was also realised. *Hali* was the term for a large plough, whch was also called *jityā* (Pāṇini.III.1.117), perhaps from its utility to break down even the hardest ground and to reclaim waste land (Agrawala, p.198).

The plough was a mark of prosperity and a householder's position was determined in terms of the number of ploughs he owned (Agrawala, p.198). A *Jātaka* story (No. 218) relates to a man misappropriating 500 ploughshares deposited with him.

The only metallic implement (Upadhyaya, 1987) of the pre-Harappan people (4th millennium B.C. to the middle of 3rd millenniu B.C.) which could have been used for agricultural purposes was axe made of copper. The furrowed field, exposed by excavations at Kalibangan (Lal) will require us to assume that ploughing or digging was done by a wooden plough or some stone implement. In the Harappan assemblage of copper and bronze implements those for agriculture are approximately 19.2% . Of these, axes of various types cover 88%, hoe, sickle and ploughshare being respectively 3.4%, 4.2%, and 4.2%. The excavators have not reported any ploughshare, but, according to Upadhyaya (pp. 42-43) five implements, described as chisels, which are thin and narrow and measure 20 cm. or more (Mackay, p.473; Marshall, p.502; Vats, p.88, *see* Plates) were used as ploughshare. The Copper hoard culture, whose emergence was contemporaneous with the mature Harappan, is characterised by axes of various types, flat axe, shouldered axe, splayed axe, narrow splayed axe, bar axe, or long narrow axe and double axe, which could have been used also for clearing forests for agriculture. The large number of bar axes found in Chhotanagpur (Yule et al, pp.126-128) were possibly used as digging implements. A *Parasu*, a *Khurpi* and two suspected ploughshares [*IAR*, 1971-72, p.51, Pl.LXV(B); *IAR*, 1976-77, p. 82, Pl.LXIII(A)] have also ben noticed in the copper hoard assemblage. Copper axes are found also with the Chalcolithic cultures of Central India, Deccan and the Neolithic-Chalcolithic culture of South India.

The introduction of iron is clearly noticed first with the Painted Grey ware culture (c. 1000-800 B.C.). But agricultural implements form 4.8% of the assemblage. This includes a sickle, a hoe, and a ploughshare from Jakhera (*IAR*, 1974-75,p.44). A developed iron technology and a wider use of iron implements characterises the NBP Ware culture (c. 600-200 B.C.). But agricultural implements are still only 10% of the total. Besides axes, *Parasu* and a *Khurpi*, we have hoes, spades and spuds[10].

The sickles (Gaur, p.429; Upadhyayay, p.205) are crescent-shaped with a tang and a pointed tip. They are generally 0.5 to 1 cm. thick. The inner edge is concave and sharp, whereas the outer is convex and blunt. The ploughshare from Rupar measures 39.37 × 2.79 × 2.28 cm. The Atranjikhera specimen is smaller measuring 14.7 × 4.1×1.9 cm. Elongated, with tapering sides, it has a deep depression in the upper half for fixing it to the wooden frame (Gaur,p.429). Iron ploughshares are reported from Kaushambi and Raghuasoi (Vaisali) also. In the Megalithic culture of Peninsular India (1st millennium B.C.) the iron agricultural implements represent 18.5% of the total assemblage. The axes are divided into two categories, short broad and long narrow whch may further be subdivided into two on the basis of their thickness. The sickle from Yeleswaram is 43.91 cm.(Khan. p.48), whereas others generally measure around 18 cm. The hoes are reported to measure between 16.50 and 22.88 cm. Besides a spade, there is a broken ploughshare measuring 24.37 × 8.58 cm.

For agricultural economy the number of metal implements is not large. Corrosion does not explain the paucity satisfactorily. It is to be noted that the sites are generally urban centres. Possibly wooden ploughs and stone implements continued to be used for digging, especially by ordinary cultivators.

Ploughing

Ploughing was regarded as an important process in cultivation.It is observed in the *Śatapatha Brāhmaṇa* (VIII.2.2.5) that furrow is like the womb in which seeds are sown and casting seeds into unploughed field is like sowing seeds into any place other than the womb.

Prayers were offered for the ploughshare to plough the field properly and for the tillers to ply rightly (*Ibid*, VII.2.2.9). Mistakes in ploughing were corrected, as was done by a priest in reciting a hymn (*Ait.Br.*III.3.38). The *Milindapañho* (IV.6.47; II, p.79) notes that one of the four essential requirements for a successful crop is that the field should be well ploughed. The necessity of ploughing a field deeply was realised. Deep ploughing brings out clods of earth from the soil and increases the fertility of the field. There were distinct terms for fields cultivated twice or thrice (Pāṇini V. 4.59; *Amarakośa* II.9.9). Pāṇini (V.4.58; also *Amara* II.9.9) further provides for the formation of terms signifying ploughing done more than three times. The *Kṛṣi-Parāśara* (verses 142-43) recommends ploughing to be done five times. The first ploughing gives wealth, the third the desired object, and the fifth rich harvest. The term *śambākṛta* (Pāṇini V. 4.58) refers to a field cultivated twice from one end to another, and second time in a reverse direction. V.S. Agrawala (p.255) explains the term as referring to ploughing the furrow a *śama* or 14 *angulas* (=$10^1/_2$ inches) deep.[11]

The general practice was to plough a field before scattering seeds. But another parctice of long standing required the field to be ploughed after the seeds had been sown. There were special terms to refer to this practice (Pāṇini V. 4.58; *Amara*, II.9.8). It was fully realised that ploughing done at the right time yields an abundance of fruit (*Uttar. Ti.* I, p.10a).

The *Kṛṣi-Parāśara* attaches great importance to ploughing. It raises the act to an auspicious rite, designated as *hala- prasāraṇa* (commencement of ploughing) which is necessary for the success of cultivation (verses 152-53). The advice concerns mostly the time and method of ploughing, but the details smack of superstition and do not seem to have much practical applicability although referrring to astronomical considerations.

The *hala-prasāraṇa* is to be done in the Nakṣatras Svāti, Uttaraphālgunī, Uttarāṣāḍā, Uttarabhādrapada, Rohiṇī, Mrgaśiras, Mūlā, Punarvasu, Puṣyā, Śravaṇā and Hastā, on Friday, Monday, Thursday, and Wednesday (but not on the remaining days) and on the second, third, fifth, seventh, tenth, eleventh and thirteenth lunar mansions (but not on the first, fourth, sixth, eighth, ninth, twelfth and fourteenth). For this the sun's entrance (*lagna*) into Vrsa, Mīna, Kanyā, Yugma, Dhanuṣ and Vṛścika are auspicious, whereas inauspicious ones are Meṣa, Karkaṭa, Siṃha, Kumbha, Makara and Tulā (*Ibid.*, verses 121-24).

The owner of the field is to take bath and put on a pair of white clothes at a time when the position of the sun and the moon is favourable, duly worship the earth, the planet, Pṛthu and Prajāpati with sandal and flowers, circumambulate fire keeping it on the right, make ample gifts, besmear with honey the tip of the ploughshare and perform *halaprasāraṇa* at the left side of the field. Vasava (Indra), Śukra, Pṛthu[12] and Parāśara are to be invoked and fire, a Brāhmaṇa and God are to be worshipped. The sides of the bulls yoked to the plough are to be besmeared with butter or ghee. Facing northward, one should give an offering of milk mixed with white flowers and curd to Indra and sitting on a seat with a concentrated mind and placing the knees on the ground should bow to him. One should give without fail an offering and lamp of ghee to Marutvān and utter an incantation to Vasudhā (*Ibid.*, 139-40).

The text points out that there should not be a broken furrow. The furrows should be one, three, or five in number. The text lists a number of inauspicious portents in the act of ploughing : the plough raising a tortoise, the forced raising of and a breach in the ploughshare, the plough, *īśā*, *yuga* or the *śaula* breaking, the *yotra* snapping, the cultivator or a cow falling down or a bull running away. Likewise, a cow bellowing and licking the nose and the bulls voiding dung and passing urine are considered to be auspicious.

Plantation

Plantation requires a knowledge of a number of processes in cultivation and objects connected with them. The preparation of the soil, including its irrigation and manuring, the ploughing of the field and sowing the seeds are three main activities in plantation, which implies an acquaintance with the qualities of soil, seed and season.

(a) Soil

Experience must have made people even in the neolithic phase aware of the suitability of soil in some areas for cultivation. Originally the term *ksetra* signified an abode and not an agricultural field. In the early Vedic literature it signifies farm land. *Urvarā* was used for the fertile and *anurvarā* for the barren land. *Kṛṣya* was the arable land.

According to Oldenberg, *Khila* was the unfertile land which lay between cultivated fields. The nature of the soil as containing *sarkara* (salty), *sikatā* (sandy) and *aśmān* (stony) was recognised. The *Vājasaneyī Saṃhitā* (XVI.43) mentions lands of many kinds, such as tracts in hill area, open plains, stream land, slopes and undulating regions, flat surfaces with green pastures, low fertile regions and cultivable lands with homesteads (Roy, pp.118-20).

In ancient India there were special terms to refer to different types of land. Of these, many were based on their properties and characteristics. The consolidated list of such terms occurring in the *Amarakośa* (II.1.1-5, 9-11) includes *bhūmi* (soil in general), *mṛtsnā* (an excellent soil), *urvara* (a fertile soil for all sorts of crops), *ūṣa* (salt ground), *usara* (a spot with lime soil), *maru* (a region devoid of water), *khila* or *aprahata* (untilled or waste land), *naḍvān*, *kumudvān*, *vetasvān* and *śādvala*

(a country abounding in reeds, waterlilies, ratans or green grass), *paṅkila* (clayey or muddy soil), *anūpa* (land contiguous to water), *śarkarila* (soil full of stony or similar modules), and *siktila* (sandy soil). Some of these appear as early as the Vedic literature. These terms imply an awareness of the properties of the soil and classifying them on that basis.

In ancient India land was generally classified into three *jāṅgala*, *anūpa* and *sādhāraṇa*, on the basis of the moisture in it. *Jangala* is dry land, *anupa* is wet land and *sādhāraṇa* has moderate or average moisture.

The classification into *jāṅgala*, *anūpa* and *sādhārana* seems to have been formulated before the times of the *Arthaśāstra* of Kautilya. It refers to the *anūpa* and *jāṅgala* land (*AS*. II.24.5). This classification was adopted by the authors of medicinal texts. They mention the three types of soils and list the trees characteristic of them.

Caraka (Kalpa, 6,7) describes *jāṅgala* as the region which is full of unobstructed open spaces, where a steady and dry wind blows, which is pervaded with expansive mirages, where rivers and rivulets are scarce, which abounds in wells (on account of scarcity of water) and is full of dry and rough sands and big sandy granules. According to Suśruta (Sūtra, 35.35), it presents a flat surface, with its dull monotony enlivened by scanty growth of thorny shrubs and tops of a few isolated hills and knolls, and in which water in springs and wells accumulated during rains becomes nearly drained and strong gales of warm wind blow. Plants characteristic of *jangala* region mentioned by Caraka are Khadira, Asana, Aśvakarṇa, Dhava, Tinisa, Sallaki, Sāla, Somavalka, Vadari, Tinduka, Aśvattha, Vaṭa and Āmalakī and Sami, Arjuna and Siṃsapa.

According to Caraka (*op. cit.*,8), the *anūpa* region abounds in rivers, is bordered by seas, and is swept by cold wind. It is interspersed with rivers whose banks are decked with Vanjula and Vanira. Mountains are absent from this region. It is thickly overgrown with forest bowers, trees, verdent trees and tender creepers.

Suśruta (*op.cit.*34) describes it as the region which contains a large number of pools, is wooded and undulated with chains of lofty hills, is impassable owing to its network of rivers and sheets of accumulated rain-water, and has a gentle humid air.

Caraka (*op.cit.*, 9) describes *sādhāraṇa* region as endued with creepers, plants and trees of both the classes, the *vanaspatis* and *vanaspatyas*. According to Suśruta (*op. cit.* 36), it exhibits features common to both the classes, the *jāṅgala* and *anūpa*.

The *Suśrutasaṃhitā* also accepts the classification of soil into six each, on the basis of their distinctive odour (*gandha*), colour (*varṇa*) and taste (*rasa*) (Sūtra 37.11). It adds another classification according to the qualities of the five elements, earth (*pṛthvī*), water (*ambu*), fire (*agni*), wind (*anila*) , and sky (*ākāśa*), being predominant in them, and enumerates their characteristic features (*Ibid.*4). It describes *sādhāraṇa* soil as one which is endowed with all the properties (*Ibid.* 13). For medicinal plants it recommends soil with distinct features (*Ibid.*2). The classification of land into three types was evidently known to Varahāmihira. He does not give full details about them. But, he has listed sixteen trees that are the characteristic products of *anupa* land (*Bṛhatsaṃhitā* 54.11).

The *Vṛkṣāyurveda* of Surapāla has a separate section (verses 35- 44)[13] on determining the ground (*bhūminirūpana*). It follows the generally accepted classification of land into three: *jangala* (dry or arid land), *anūpa* (wet land), and *sāmānya* (moderate humidity land). It introduces another classification on the basis of colour (*varṇa*) and taste (*rasa*).

There are six types of soils according to their colour: *asita* (black), *vipāndu* (pallid), *śyāmala* (dark blue), *lohita* (red), *sita* (white) and *pīta* (yellow). Likewise, they are classified into six according to their taste: *madhura* (sweet), *āmla* (sour), *lavaṇa* (saline), *tikta* (pungent), *kaṭuka* (acrid) and *kaṣāya* (astringent). The soil, that is full of poisonous matter, stones or ant-hills or is saline, gravelly and has underground water too deep, is not favourable for trees. That soil is praiseworthy which is of mild colour like saphire (*indranīla*) and the plumage of a parrot, is white like a conch, jasmine (*kunda*), water-lily (*kumuda*) and moon, and vies with molten gold and blossoming Campaka. In a soil which is even (*sama*), contiguous to water, full of sprouts of green trees and grass, trees of all kinds thrive when planted at proper places. The land which is of moderate humidity (*sādhāraṇa*) and not dry (*jāṅgala*) nor wet (*anūpa*) is good and all kinds of trees grow on it without doubt.

Panasa, Lakuca, Tālī, bamboo, citron (Jambīra), rose-apple (Jambū), Tilaka, fig-tree (Vaṭa), Kadamba, hog plum (Āmrāta), date-palm (Kharjūra), arecanut (Pūga), plantain (Kadalī), Tinisa, red-grape vine (Mṛdvi), Ketakī, coconut and others are trees that grow on *anūpa* land. Śobhāñjana, Śrīphala, Saptaparṇa, Śephālikā, Aśoka, Śamī, Karīra, Karkandhukā, Kesara, Nimba and Soka flourish on *jāṅgala* land. Citron (Bījapuraka), Punnāga, Campaka, mango, Atimuktaka, Priyaṅgu, Pomergranate are trees that grow on *sādhāraṇa* land.

These verses occur in the *Upavanavinoda* (verses 35-44), which is a part of the *Śārṅgadharapaddhati* (Raychaudhuri, pp.9-10). They have been evidently borrowed from the *Vṛkṣāyurveda* of Surapāla.

Varāhamihira regards soft (*mrdvi*) to be good for all kinds of trees. He emphasises the need for preparing the soil before sowing. The first process in preparing the land is to sow sesamum in the soil and, when they grow and have put forth flowers, they are to be uprooted (*Bṛhatsaṃhitā* 54.2).

(b) Seeds

Surapāla, in his *Vṛkṣāyurveda*, dealing with plants (*pādapa*) in general, including big trees (*vanaspati*), trees (*druma*), creepers (*latā*) and thickets (*gulma*), mentions three ways of planting them, namely, by seeds (*bīja*), scion of a plant (*kāṇḍa*) and bulbous root (*kanda*). It lists different groups of plants that grow from seeds and scions, from bulbous roots, and from both seeds and bulbous roots (verses 45-51).

Varāhamihira makes a special mention of the fact that certain trees grow from scion and not from seeds. The scions are plastered with mud. These trees are Panasa (bread-fruit tree), Aśoka, plantain, rose-apple, Lakuca, pomegranate, Drākṣā (vine), Pālīvata, Bījapūra (citron) and Atimuktaka. They are to be carefully planted by taking their stem or by digging them up from the roots (*Bṛhatsaṃhitā*, 54.4-5).

A passage in the *Milindapañho* (IV.6, 47; II, p.79) implies a clear appreciation that the knowledge about seeds has two main parts - the selection of good seeds and sowing them in a proper manner.

Through experience the cultivator had realised that all seeds do not germinate. According to a passage in the *Milindapañho* (IV.1.64; I,p.193), the failure of a seed to germinate is, to a great extent, due to defects. The similies based on infertile seeds imply a general awareness of the properties of a seed. The *Mahābhārata* (XII.320.33) refers to parched grains as seeds unfit to grow. The *pulākā* grains mentioned in the *Mahābhārata* (XII.181.7) are explained by Nīlakantha as those rendered incapable of growing due to the excessive underground heat. Another passage in the *Mahābhārata* mentions the fruitlessness of *ṣaṇḍa-tilas* and *kākayavas* (II.77.13). According to Nīlakaṇṭha, *kākayavas* is a term for a seed separated from its outer skin and thus rendered unproductive.

The collection of seeds in the appropriate time (*yathākālam*) was of great importance for the success of cultivation. The *Arthaśāstra* mentiones it as the first duty of the Superintendent of Agriculture (*sītādhyakṣa*). He is required to collect in the proper seasons seeds of all kinds of grains, flowers, fruits, vegetables, bulbous roots, roots, creeper fruits, flax and cotton (II.24.1).

The *Kṛṣi-Parāśara* (verses 157-67) is more detailed and specific. It requires seeds to be collected either in Māgha or Phālguna. They are to be dried up thoroughly in the Sun. The chaff is to be removed. The seeds which are uniform are to be collected. They are to be kept in a very tight packet and the grass that has come out is to be cut. The advice about the preservation of the seeds is mixed up with traditional notions about sacramental purity. Seeds are not to be kept on an ant-hill, in the cowshed, the place where a woman has delivered a child, or a house having barren women. They are not to come in contact with remnant food, a woman in menses, a barren woman, a pregnant woman, or a woman who has just delivered. Ghee, oil, butter-milk, lamp and salt are not to be kept on seeds. Seeds, kept in contact with a lamp, fire or smoke, or damaged by rain, or kept in pits or underground, are not to be used. Likewise, seeds, which are mixed up or are chaff or mixed with particles, become barren.

To increase the fertility of the seeds they were treated before sowing. According to the *Arthaśāstra* (II.24.24), seeds of grains are to be soaked in dew and dried in the heat for seven days; those of pulses for three days and nights or five; stalks that serve as seeds are to be smeared at the cut with honey, ghee and pig's fat mixed with cow-dung; bulbous roots to be smeared with honey and ghee; and stone-like seeds to be smeared with cow-dung.

The *Vṛkṣāyurveda* (verses 52-58) of Surāpala deals with the treatment of seeds in some details. It requires the seed to be extracted from a fruit that has ripened in due season and dried. The seed is to be soaked (*niṣicya*) in milk. It is to be besmeared (*lipta*) with the ashes of Brhati and sesamum and ghee and is to be rubbed well (*parimardita*) in cowdung. Then it is to be dried in shade for five days. After it has dried, it is to be rubbed repeatedly in honey and the powder of Viḍaṅga or in the ashes of Bṛhati, sesamum and Nala mixed with mustard.

It is to be fumigated with the fumes (*dhūpayet*) of ghee mixed with Vidanga, or of fat. The treatment is specially recommended in the case of seeds of mango (Makanda), rose-apple (Jambu) and bread-fruit (Panasa)[14].

Varāhamihira prescribes the method for treating seeds for increasing their fertility. For ten days daily the seeds are to be handled by hands smeared with ghee and soaked in milk. Then they are to be repeatedly rubbed with cowdung. They are to be fumigated with the fumes of the flesh of hog and deer and are to be sown mixed with meat and the fat of hog (*Bṛhatsaṃhitā*, 54. 19- 20). Tintidi and other seeds are to be sprinkled with combination (*saktu*)[15] of powder of rice, Māṣa and sesamum mixed with putrid flesh and regularly fumigated with the fumes of turmeric (*Ibid.*21). Kapittha seeds are to be placed in milk which has cooled down after boiling in the eight roots (*aṣṭamūlī*) consisting of Āsphoṭa, Dhātrī, Dhava and Vāsikā, Vetasavallī and Sūryavallī with leaves, Śyāmā and Syandanaka for *tālaśata*[16] and then dried in the Sun. This process is to be repeated daily for a month (*Ibid.*, 22-23). A fourth method is to sprinkle the seeds a hundred time with the paste made of he fruit of Aṅkola or the oil made of it from the fruit of Śleṣmātaka (*Ibid.*27). The shell of the seeds of Śleṣmātaka is to be removed and then treated with the lubricous fluid of Aṅkola and then dried in shade. This is to be repeated seven times. Then they are to be rubbed in the dung of buffalo and put in the dry dung of the same animal and then mixed with hail and soil (*Ibid.*,29-30).

The prescription about the treatment of seeds is not without some scientific basis. If the seeds are soaked in any solution, the decayed ones will float and can easily be detected and discarded. The application of cowdung, honey, butter, etc., would protect it from insects and diseases. The cowdung, being hygroscopic and containing potassium, nitrogen and phosphates and also microbes, is expected to help germination.

(c) Sowing

Sowing being an important process in cultivation, it was given serious attention and care. Befitting its importance solemn religious rites were performed on the occasion. Panini (IV.3.45) shows that farmers selected auspicious days for sowing seeds; the full-moon day of the month of Agrāhāyana was one such auspicious day. The *Arthaśāstra* (II.24.27) advises the Superintendent of Agriculture (*sītādhyaksa*) at the first sowing to sow the first handful after immersing it in water containing gold and recite the *mantra* meaning "Salutation to Kāśyapa, the Lord of Creation, and to the god (of rain) always. May the divine Sītā prosper in my seeds and my grains". The *Vṛkṣāyurveda* (verse 59) of Surapāla requires the master to bathe and become pure, put on clean clothes, worship the gods, salute the preceptor, make the gift of money or land to a meritorious person, make obeisance to the presiding deity of the land (*vāstupuruṣa*) and then himself first sow a few seeds, after which the attendants are to sow all over the field.

A significant development in regard to sowing was the practical realisation of the quantity of seed required for sowing in a particular field. Pāṇini (V.1.45-46) provides for the formation of terms to refer to fields according to the quantity of seed sown in them. These and other distinctive terms are found in the *Amarakośa* (II.9.10) also. The literary references are confirmed by epigraphic records, which,

in mentioning the fields (*kṣetram*) granted, specify the quantity of seed required to sow them[17]. The cultivator was also required to know how seeds of a particular type were to be sown, thickly or sparsely (Medhātithi on IX.330)

The selection of one of the crops of a particular crop season depended to a great extent on the amount of water available (*AS*.II.24.19). The *Arthaśāstra* (*AS*. II.24.22) says that a region where the foam strikes (river bank) (*phenāghāta*) is suited for creeper fruits; regions on the outskirts of overflows (*parīvāhānta*) for long pepper, grapes and sugarcanes; those on the borders of wells (*kūpaparyanta*) for vegetables and roots; those on the borders of moist beds of lakes (*haraṇiparyanta*) for green grasses; and ridges (*pālya*) for plants reaped by cutting, such as perfume plants, medicinal herbs, *uśīra* grass, *hrībera*, *piṇḍāluka* and others.

(d) Sowing Methods

The earliest primitive method of sowing was that of individual planting or dibbling of seeds into holes made by digging sticks. With the coming of field-tillage the method of broadcasting or scattering was introduced. We can speculate that in neolithic times, when cultivation was generally of the shifting or jhuming type, sowing was done either by dibbling or by broadcasting.

S.R. Rao (p.79) has identified the figure of a seed-drill on an Harappan seal from Lothal (Randhawa, p.157). This will mean that the Harappans practised line-sowing by using seed-drills. The inference receives support from the pre-Harappan ploughed field exposed by excavations at Kalibangan (Lal, pp. 1-4). The furrows reveal a grid pattern running at right angles to each other, the north-south ones having an average distance of 1.9 meters and the east-west having 30 cm. only. The present practice in Kalibangan in fields with this ploughing pattern is taken to suggest that this was done for mixed cropping, the horizontal furrow for sowing one crop and the vertical for another.

The Ṛgvedic references are not very explicit about the sowing method. One passage (*ṚV*. X.9.23) says "Harness the ploughs fit on the yokes, now that the womb of the earth is ready to sow the seeds therein". Aiyer(p.16) interprets it as showing that seeds were "either sown in plough furrows or broadcast and then covered over by ploughing". Another passage (*ṚV* X.101.3-4) has a similar import. "Attach the 'sira' (plural) spread apart the yokes, sow the seeds into the prepared womb". These two passages will suggest that after an initial ploughing the seeds were sown with the help of a plough. J. Bloch also interprets *sīram* occurring in the passage as a plough used for sowing seed. This is evidence of sowing by a seed-drill plough.

We do not have any undisputed reference to the method of sowing rice by transplantation before c. 500 B.C. The terms *ropaṇa* and *ropeti* occurring in early Pali literature refers to transplantation. In the *Aṅguttara Nikāya* (I. 239-40) the expression *bijani* patitthapeti is explained as meaning 'plants seedling', *patiṭṭhapeti* being the forerunner of the present terms *biṭhauni* current for this practice in parts of north Bihar and *biya* (from *bīja*) signifying seedlings for planting. In the Jain text *Nāyādhammakahāo* (vii.68, p.85) there is a reference to five paddy grains being sown on a well prepared bed and the seedlings being transplanted twice or thrice.

The expression for transplanting is *ukkhayanihae* or *ukkhāyanihae* which literally means 'uprooted and planted' (Jain, p.122). It has been suggested that the distinction between the Vedic term *vrīhi* and the post-Vedic *śāli* is that the first is grown without transplanting, whereas the second is grown by transplantation (P.B. pp. 122,204). Greek writers refer to the practice of wet paddy production and transplantation. Aristobolus says that rice crop stands in water enclosure and is sown in beds (Majumdar, p.251). Megillus, as quoted by Strabo, mentions that rice cultivation was by transplanting (Majumdar, p.251).

The usual practice was to sow the seeds after the field had been ploughed. This is indicated by numerous literary accounts, which, in describing the sowing processes in cultivation, speak of the sowing of seeds in a field that has been carefully tilled [*Śat.Br.* I.1.6.3 ; *Cu.V.* VII. 1.2 ; *Mil.* II. p. 269 f(VI.22)]. Generally seeds were scattered by hand (Ray, pp.100, 120). We get an idea of the method of sowing seeds from a verse in the *Mahābhārata* (VII.25.31) which compares it with the throwing of arrows in quick succession. But there were some other methods as well. In the *Matsyapurāṇa* (Ch. 154.404), the Ṛṣis, who approached Śiva for Umā's marriage with him, when returning, bent their bodies before Śiva as done by a farmer in sowing seeds. This may be interpreted as referring to the practice of line-sowing in which the farmer, in dropping seeds in the furrows, keeps his body in a drooping position. Panini mentions the term *bījākaroti* (V.4.58), which is explained by the *Kārikā* to mean tilling along with the seeds (*saha bījena vilekhanaṃ karoti*). This suggests a device by which a cultivator sows the seeds in the line of tilling through a cone attached to the pole of the plough (Agrawal,p.200). Medhātithi (on Manu II.112) also refers to seeds being sown with the help of the plough.

(e) Transplantation

Kālidāsa (*Raghuvaṃśa*, IV.20,37) makes an apt reference to the practice of the seedlings of *śāli* being uprooted and then transplanted at another place. The *Kṛṣi-Parāśara*, in laying down the processes in cultivation, has in mind the details of paddy cultivation. It prescribes the procedure of transplantation (*ropaṇa*) (verses 183-185)[18]. It envisages the sowing of seeds for transplantation (verses 169,172). It classifies seeds into two, those which are sown and those which are later transplanted. Sowing is free from defects, but transplantation is attended with maladies.For transplantation seedlings are not to be gathered (*bījakarṣaṇa*) from full grown (*vṛksarūpam*) paddy plants, because all seedlings, grown hard in fields, do not yield fruit. Seedlings are to be transplanted one cubit from one another in Karkaṭa (Śrāvana), half a cubit in Siṃha (Bhadra), and four fingers apart in Kanya (Asvina). The text requires the cultivator to perform the *kattana* (possibly meaning thinning out) of paddy in the month of Āsāḍha and Śrāvaṇa, without which there is an indifferent and poor growth of paddy. But *kattana* and plantation are not to be done in a low land (verses 186-88). The removal of weeds (*nistṛnikaraṇa*) from paddy is to be done between Kulīra (Śrāvaṇa) and Bhādra. Agriculture suffers loss due to weeds. Agricultural produce from which weeds are removed becomes highly fruitful (verses 189-92). The text further advises that in Bhādra water is to be

drained off, preserving it up to the roots only. This will keep paddy free from disease (verses 193-94). Water is to be preserved in Āśvina and Kārtika (verses 196-97).

Varāhamihira records some practical hints about transplatation of trees. Plants that have not put forth branches are to be transplanted (*praropayet*) in the winter, those that have put forth branches, in the beginning of winter, and those that have developed trunks, at the advent of the rainy season (*Bṛh. S.* 54.6).

The trees are to be transplanted (*saṅkrāpanaviropana*) after plastering them from their root up to the branches with ghee, *uṣīra*, sesamum, honey, *viḍaṅga*, milk (*kṣīra*) and cowdung (*ibid.*7). To emphasise the importance of transplantation the person was required to be pure and clean and to perform religious rites. The transplanted trees are to be watered both morning and evening during summer, on alternate days in winter, and during the rainy season when the soil becomes dry (*ibid.*9).

Varāhamihira (*Bṛh.S.* 54.12-13) brings out the importance of proper spacing in planting trees. The best kind of planting is that in which the trees are planted at a distance of twenty cubits (*hastas*) from each other, the middling one when they are sixteen cubits apart, and the worst when they are at a distance of twelve cubits from each other. Trees that grow too close and touch each other do not yield adequate fruits owing to their roots entwining and injuring each other.

In its chapter (282) on *Vṛkṣāyurveda* the *Agnipurāṇa* deals with the planting (*ropana*) of trees. It mentions the religious rites to be performed and the asterism under which it is to be done (verses 3-4). When the earth is dry, the planted trees are to be watered each morning and evening in summer, on alternate days in winter, and in the night in the rainy season (verses 7-8). It considers a distance of twenty cubits (*hastas*) between the trees to be best, of sixteen to be middling, and of twelve to be the inferior most. Trees planted too close become fruitless, hence they are to be chopped off in the beginning (verses 8-9).

The *Vṛkṣāyurveda* of Surapāla gives directions about the plantation of trees in the section called *vapanavidhi* (the method of sowing). Trees are to be sown or planted on a land which is even and pleasant and in which flowers, sesamum and Masa have been scattered (verse 63). The distance of fourteen, sixteen or twenty cubits between trees is considered respectively to be bad, middling and excellent (verse 64). The interval between thickets (*gulmas*) may be four or five cubits and that between Puga (arecanut) etc. two or three cubits (verse 65). If the gap is larger than prescribed, there is danger to the trees from storm and, if it is less, the fruits will be poor (verse 66). Sowing and especially planting of mangoes, pomergranates etc. and pumpkin gourds Alāmbuka is to be done in a pit measuring one cubit all round, dug long back, dried, filled with cow-bones and cowdung, well burnt and allowed to cool down naturally, and then after removing the ashes irrigated with carcass water (*kuṇapa*) and filled with manure (verses 67-69).

The *Vṛkṣāyurveda* of Surapala mentions the months for planting various trees; Kṣirikā, mango, pomergranate, and Bakula etc. in Śrāvaṇa, Rāja, Kośāmra[19], and Lakuca etc. in Bhādṛa, (verse 87), Golla and brinjal (Vārtāka) etc. in Āśvina, majoram (Phanijja), Śatapattrika, coriander (Dhānyaka) and Mūlaka etc. in Kārttika (verse 88), Paṭola etc. in Phālguna, Karkāruka etc. in Caitra and plantain etc. in

Vaisakha under Sukra (verse 89). In Āṣāḍha all sorts of seeds may be sown and trees may be planted at will. Sahas (Mārgaśirṣa), Sahasya (Pauṣa) and Māgha are forbidden for sowing etc. (verse 90).

Pesticide

In reference to plants, Pest signifies any insect, fungus, etc. which destroys plants. Pesticide means pest-killer.

The major calamities, termed as *īti*, were traditonally enumerated as being six: excessive rain, drought, locusts, rats, parrots and foreign invasions[20]. All these have a reference to agriculture. The term *īti* signifies an infectious disease also, but we do not find any reference to its application for the diseases of the plants.

In the Vedic literature we find prayers to Indra and Rudra for protecting crops from drought and lightning (*ṚV.* VI. 50.1-3; VI.142.1). For warding off harmful insects several spells and rites are prescribed. The *Atharvaveda* voices the anger against insects harming the field: "O Aśvins, slay the *tarda* (borer), the *samanka* (hook) and the mole, cut off their heads and crush their ribs, shut their mouths, that they shall not eat the barley, free the grain from danger. Ho *tarda*, locust, *gabhya* (snapper), *upakvasa* do get out, not eating this barley, without working injury. O husband of the *tarda* (female), husband of the *bhaga* (female), of the sharp teeth, listen to me. The *vyadvaras* (rodents) of the forest, and whatever other *vyadvara* there are, all these we do crush".

The *Agnipurāṇa* (282, verses 10-13) prescribes a few treatment to promote the growth of flowers and fruits and overcome infertility. After plastering the plants with mixture of Viḍaṅga and ghee, they are to be sprinkled with cold water mixed with Kulattha, Māṣa, Mudga, barley and sesamum. It recommends sprinkling with ghee and cold water as a general remedy. The powder of the offal matter of sheep and goats, barley powder, sesamum, beef, and water are to be kept burried for seven days and then are to be sprinkled on plants. The plants are to be irrigated with the washings of fish.

The *Agnipurāṇa* (282. verses 13-14) mentions fish and meat mixed with pulverised Vidaṅga as a pregnancy craving of the trees and a general cure for all their diseases.

For the protection of crops from diseases and pests people resorted to measures which were a strange amalgam of superstitious rites and practical application. The subject was covered by the science of *vṛkṣāyurveda* or medicinal science for plants. The use of the term *āyurveda* led to the application of certain principles characteristic of the science of *āyurveda* to that of *vṛkṣāyurveda*. One such principle is that of *tridoṣa*, the three humours, whose disorder leads to various ailments. In the case of plants also the disorders of wind (*vāta*), bile (*pitta*) and phlegm (*kapha*) are taken to result in various defects of plants.

The *Vṛkṣāyurveda* of Surapāla[21] has two sections, one the knowledge of the diseases of trees (*rogajñāna*) (verses 165-183) and the other on the treatment (*cikitsā*) of the diseases of plants (verses 184-222). Surapala introduces an element of systematic classification in its account of the diseases of the trees. He says that

the diseases of all species of trees may briefly be classified in two groups, the internal or those arising from the body, and the extraneous or those attacking from outside (verse 165). The bodily or internal diseases arise from the disorders of wind (*vāta*), phlegm (*pitta*) and bile (*kapha*), and the extraneous diseases and ailments are caused by vermin (*kīṭa*), frost (*śīta*) etc. (verse 166).

The text gives characteristic features of trees suffering from these diseases (verses 167-172). It describes the trees as afflicted with excessive heat (*caṇḍatāpa*), hit by the velocity of a gale (*pavanodvega*), drying of their parts (*angapariśoṣaṇa*) and injury (*vraṇa*) (verses 173-76). It lists some of the important causes for the decline of trees (verses 177-80, 182). It says that putrid smell, absence of smell, and shrivelling of leaves and sprouts are caused by the affliction of ants (*pipīlika*) and indigestion caused by excessive watering (verse 181).

The text prescribes cures for trees suffering from the disorders of wind, phlegm and bile (verses 184-92). It gives detailed advice about the treatment of trees infested with insects (verse 193-98). Kāṇḍāraka and other insects (*kṛmi*) are to be taken out from the roots of the tree which is then to be sprinkled with cold water for seven days. For destroying insects the text recommends administering of water containing milk, carcass water (*kuṇapa*), Bhillota, Vacā and cowdung, plastering of Siddhārtha, Abda, Vacā, Kuṣṭha and Ativiṣa, and fumigation with the fumes of Siddhartha, Ramaṭha, Vidanga and Uṣana and of washings of beef, horn of buffaloes and flesh of a pigeon, along with the powder of Bhillata. Another recommendation is to plaster with Viḍaṅga mixed with ghee, irrigate with alkaline water (*kṣārāmbu*)[22] for seven days and poultice of beef, Siddhārtha and sesamum. A worm-eaten plant is to be irrigated with a solution of oil-cake in water. Insects on leaves are destroyed by dusting them with ashes and brick-dust. Injury caused by insects is healed by a plastering of Jantughna, sesamum, cow's urine, ghee and Siddhārtha and by watering with milk.

The text recommends treatment for trees damaged by frost and scorching heat (*hīnacaṇḍātapa*) (verse 199), broken trees (verses 200-201), trees with branches fallen off (verse 203), trees burnt with fire (verses 204-205), trees struck with lightning (verse 206), trees shrivelled with fire (verse 207) or by sterile soil (verse 208) or want of water (verse 209). It further prescribes treatment for wounds (*vraṇa*) of trees (verse 210), defluxion (*parisrāva*) (verse 211), diseases caused by wrong nursing (*mithyopacāra*) (verse 212), jaundice (*pāṇḍuroga*) (verse 213), barrenness (*vandhyā*) (verses 214-18) and indigestion caused by water-logging (*ajīrṇāmbu*) (verse 219).

Vegetables (*śākajāti*) like cucumbers are to be treated by fumigating them with the bones of cow and dog and the ordure of a cat (verse 220). Saplings are not to be administered pungent susbtances nor are they to be fumigated (verse 221). If the treatments do not respond, the trees are to be transplanted in a soil of better quality (verse 222).

Varāhamihira (*Bṛhatsaṃhitā* 54. 14-15) deals with the question of the diseases (*roga*) of trees in a matter-of-fact manner, without importing any of the notions associated with the science of *ayurveda*. He lists four such diseases : searing of leaves (*pāṇḍu patratā*), arrest of the growth of leaves (*avṛddhi*), drying up of the branches (*śakhāsoṣa*) and excessive exudation of the sap (*rasaśrūti*) and attributes

them to cold, wind and sun (*sitavatatapa*). The remedy recommended is to clear the afflicted part first with the help of a weapon[23] and then to plaster them with Vidanga and ghee and sprinkle them with water mixed with milk.

There was a widespread practice of using magical spells (*mantras*) to ward off diseases, insects, birds and beasts destroying the crops. In the *Kṛṣi-Parāśara* it is termed as the pest-killing spell (*vyādhikhaṇḍanamantra*). The *mantra* was written on a leaf and then placed in the field. The practice is evidenced by the *Kṛṣi-Parāśara*, *Vṛkṣāyurveda* of Surpāla, *Upavanavinoda* and the *Jyotiṣtattva* of Raghunandana[24]. There are slight variations in the details of the *mantra*. In the *Kṛṣi-Parāśara* it is in the form of an imperial order by Rāmacandra to Hanuman to ask the pests to leave the field of a certain person; they are to be beaten by Hanumān witht his tail, if they do not comply. One manuscript of the *Kṛṣi-Parāśara* adds a second *mantra* in which Hanumān orders the pests to destroy themselves. The pest averting incantation in another school[25] presents the command of Rāmacandra in a changed form. Here the pests are said to be the demoness Triputi and her seven sons in disguise. Hanumān is to strike them with his tail and, tearing them with his nails, throw them in the southern sea. If he tarries even for a moment, he is to be cursed by his father Keśarin and mother Anjanā, and will be disowned by Rāma as his servant.

In the *Vṛkṣāyurveda* of Surapāla (passages 161-63) the *mantra* and its use are provided in a different manner. The *mantra* says that Hanumān orders and destroys the rats, birds, ants, etc. From Kiṣkindhā Lord Hanumān orders mice, bugs (*gandhikā*), locusts (*śalabha*) etc. in a field that, on seeing this royal order, they are to leave the field and go elsewhere, otherwise they will be beaten and destroyed by his tail. This spell is to be written on a leaf, to be recited, and then buried under the earth. This will destroy the sparrows (keca=*keñca*), worms (*kita*), flying insects (*pataṅga*), mice (*ākhu*), ants (*pīpīlī*) etc.

The spell was incorporated with some changes and elaborations in a few other texts and anonymous manuscripts. In the *Upavanavinoda* (VII.2) the incantation is recommended to be used when there is an apprehension of danger from locusts, rats, birds and ants. It is to be muttered one hundred and eight times before being written on a leaf. In it Hanumān commands the vermins, rats, birds, ants, locusts, young elephants, cranes, insects, *gandhikā*, *bimbī* etc. In the *mantra* occurring in one manuscript of the *Vṛkṣāyurveda* of Surapāla[26] those who are happy at the feet of Śrī Rāmcandra command Hanumān to destroy the pests, the harvest-destroying brood of demon Taraka, not dispersing from the field.

The element of popular superstition is clearly discernible in regard to the pests listed in the *mantra*. In one source[27] the incantation mentions the demoness Triputi and her seven sons as being in the guise of pests like *bhombha*, *bhombhī*, *pāṇḍaramukhī*, *gāndhī*. *dhūliśṛṅgī*, etc. In one manuscript of the *Vṛkṣāyurveda* *simasira*, *ratri*, *hira*(?),*paṇḍara*, *bhūdika* (?), *lapoka*(?), *dhuli*, *siṃhi*, *gabhandaka* etc. and *subhranaka* (?), *cakata* (?), *kata* (?), hogs, deer, buffaloes, rats, etc.are the harvest-destroying brood of the demon Taraka.

Besides the names mentioned above, the *mantra* in the *Kṛṣi- Parasara* lists *vata*, *bhāmbhā*, *bhāntī*...(?), *śaṅkhī*, *gāndhī*, *pandramuṇḍi*, *dhūliśṛṅgārī*, and *kumarimaḍaka* as well as *ajā*, *ghataka*, *śuka* (parrot), *śūkara* (pig), *mṛga* (deer),

mahiṣa (buffalo), *varāha* (boar), *pataṅga* (locust) etc. The additional *mantra* occuring in one manuscript of the *Kṛṣi-Parāśara* mentions *kṛmi* (worm), *kīṭa* (insect), *patanga* (flying insect), *mūṣika*, *vātā*, *bhāmbhā*, *bhāmbhī*, *pāṇḍuramuṇḍi*, *dadhitanka*, etc. In all these lists one can easily distinguish the names of insects, birds, ants, locusts and rats from other names. These names cannot be explained with the help of lexicons[28]. They are imaginary and refer to evil spirits. But the possibility cannot be ruled out that they were used for diverse types of insects and worms, of not much consequence otherwise, which were harmful to crops. It would appear that no effective pesticide was developed for checking their harmful effects.

In the *Śārṅgadharapaddhati* (verses 3017-18) it is said that if sand in a pot empowered with *mantras* is thrown in the field, insects, cranes, parrots, boars, deer, rats and hares keep away.

The *Kṛṣi-Parāśara* advises the performance of the rite of planting a reed (*nalaropaṇa*) in a paddy field (verses 198-205). It was performed so that all the paddy plants, tender, young and old, the largest and the smallest, the diseased and the healthy, be of uniform growth and yield abundant produces. Thus, the rite was intended to remove the diseases of the plants, including the pests that afflicted them. On the Kārttika-Saṅkrānti day a *nala*, along with leaves, was planted on the north-east corner of the field with a prescribed incantation, and the *nala* and the paddy plants were to be worshipped with suitable offerings. The rite is taken to be similar to the practice, prevalent in Bengal, of fixing poles of various designs, in order to scare away mischievous birds and beasts (Majumdar and Banerji, Introd.p.XVI). This shows that, in place of pesticides, the cultivators resorted to magico-religious rites.

The extent to which pesticides were used to protect crops is only to be speculated. We do have evidence for measures to protect crops from wild animals and birds, but we do not have any specific reference to the use of pesticides. It is significant that the *Kṛṣi-Parāśara*, which relates to agricultural practice, does not refer to pesticides. For warding off the menance of diseases, insects and malicious animals (*vyādhīkiṭahiṃsra*) it refers to the magico-religious rite of tying in the midst of the crops a leaf with a *mantra* written on it (verse 195). It is only in reference to trees and plants that the protective measures and pesticides are detailed in the ancient texts. It will remain debatable if the ordinary cultivator could afford the costly recipes meant for the well-to-do owners of gardens and orchards.

The only reference to the use of pesticides in Sanskrit literature, which we have been able to trace, occurs in the *Kāśyapīya-Kṛṣisūkti*[29]. Here also, it is to be noted, there is no advice to the application of the pesticide to rice, pulses, grains, and other crops. It is in connection with the cultivation of vegetables that the pesticide is recommended. The text says that if vermins etc. are eating the leaves of the vegetables etc. or egg plant (*vārtāka*), small cucumber (*paṭolikā*), *vallī*, *śavaka*, pumpkin gourd (*kūṣmaṇḍa*), *kalata* (?), *surana*, *śakuta* (?), turmeric (*haridrā*) and ginger (*ārdraka*), the blades are to be systematically sprinkled with ash-dust and lime-water to remove the damage caused by vermins. It can be surmised that the cultivator used these pesticides in the case of grains and other crops as well. Though the text seems to be a medieval work, we may not be wrong in suggesting that this traditional knowledge of rudimentary pesticides went back to ancient times.

Manuring

The surplus economy of the Harappans may imply the use of fertilisers, but their nature and extent cannot be determined. The evidence about the use of manure in the Vedic period is not clear. Some scholars take the terms *karīsa*, *śakrt*, *śakan*, *śāka* and *śaka*, meaning cowdung, to stand for cow-dung manure (Satavalekar, pp.19-20; Macdonell and Keith, I, p.182). A passage in the *Ṛgveda* (I. 151.10) speaks of Rbhus separating the *śakṛt* from other parts. The word *karīṣa* occurring in the *Śatapatha Brāhmaṇa* (II.1.1.7) denotes dry cowdung. Cowdung was collected in cowstalls (*Atharvaveda*, XII. 3.4). It is not unlikely that cowdung was used, as in modern times, both as fuel and manure, but there is no clear reference to its use as manure. The *Atharvaveda* (III. 14.5) provides the only positive reference in mentioning cowdung as a useful manure for the *śāli* variety of rice.

The *Arthaśāstra* (VII. 11.9) observes that the qualities of land (*bhūmi*) can be contrived (*kṛtrima*). The expression (*kṣetra-śodha* occurring in the *Rāmāyaṇa* (I.66.13-14) means improving the field and implies the use of fertilisers. The *Kṛṣi-Parāśara* (verse 111) recognises the importance of manure for crops and says that without manure the paddy simply grows up, but does not yield any fruit. We cannot determine the stages through which the knowledge and use of manures originated and grew.

The first systematic account of agriculture which is available in the *Arthaśāstra* (II. 24.24-25) refers to the treatment of seeds, but not to the application of manure to the soil. But, there are indications that the fertilising qualities of cowdung, cow-bones, fish and green manures were not unknown; these were used for plants and not crops.

The actual practice about the use of manures is best recorded in the *Harsacarita* (p.65). Bāṇa gives a very graphic picture of heaps of old and rubbish things together with cowdung (*purāṇapāṃsūtkirakarīṣakūta*), brought in carts, being applied for the improvement of fields that had become weak in their fertility properties.

The *Kṛṣi-Parāśara* is the only text which records the method of preparing manure out of cowdung (verses 107-9). It says: in the month of Māgha (January - February) a dung heap is raised with the help of a spade. When it is dried in the sun, smaller balls are made out of it. In the month of Phālguna (February-March) these dried balls of dung are placed into holes dug for the purpose in the fields, and at the time of sowing they are scattered in the field'. Apparently the author of the text cannot be expected to have identified the component elements of the cowdung manure, but, possibly, he was aware of its fertilising properties and also appreciated the way in which they could be preserved and increased. Gangopadhyaya (pp. 58-59) analyses this method of preparing the dung manure and shows that the practice of not disturbing dung-heap means the minimisation of the loss of nitrogen, the chief fertilising element, that of drying dung into balls results in reducing active ammonia which may be injurious to the plants, while that of placing the dung balls in pits increases humus that contributes to the fertility of the soil.

Some other manures are suggested in texts on *Vṛkṣāyurveda* (the science of plant life). The term is not restricted to the diseases of plants and trees and their treatment, but covers other aspects of their healthy growth. It can be traced in the *Arthaśāstra*

(II. 24.1). The earliest available account of the science in the *Bṛhatsaṃhitā* contains some prescriptions about manure. It advises seeds to be sown in a *parikarmita* soil (*Bṛh.S.* LIV. 20). Bhattotpala explains the term to mean a soil in which sesasum was previously sown. The *Bṛhatsaṃhitā* prescribes that a circular hole (*avata*), a cubit in diameter and two cubits deep, is to be dug and then filled with the milky decoction. When it dries up, it is to be burnt with fire and then pasted over with ghee and honey mixed with ashes. It is to be filled first with soil (*mṛttikā*), then with the powder of bean (*māṣa*), sesamum (*tila*) and barley and then again with soil. Finally, sprinkling the soil with the washings of fish and meat, it should be beaten and reduced to a thick consistency (*Ibid.* 24-25). The text further advises that for a proper inflorescence and fructification the plants are to be watered with a mixture of two *āḍhakas* of powder of the excreta (*śakṛt*) of goats and sheep, one *adhaka* of sesamum, one *prastha* of barley powder (*śaktu*), one *droṇa* of water and one *tulā* of beef, all kept together for seven nights.

The only Sanskrit text, other than the *Kṛṣi-Parāśara*, which refers to the application of manures to cultivable land, is the *Kāśyapīyakṛṣisūkti*. In the section (VI) dealing with the work done at the time of the commencement of agriculture, it says that, after duly ploughing the field, the cultivator should place in it cow-dung, goat-dung, or compost (*vālaga*) in order to increase its fertility (verses 263-64). In section XIII, dealing with the method of cultivation to be followed for various grains, it advises that paddy seedlings are to be transplanted in a rice- field softened by ploughing and carefully manured with goat-dung and cow-dung with *latā* and *vratati* (verse 431)[30]. Later, in the same section, exhorting the cultivator to do cultivation twice every year, it says that "it is desirable that the second cultivation is to be done after having raised the fertility of the soil by manuring with goat-dung or cow-dung or compost etc" (verse 513) (Raychaudhari, p.68, verse 477). In section XIV, dealing with the cultivation of pulses and other grains, the cultivator is advised to apply rich manure to the root of each seedling after weeding (verse 551) (Raychaudhari, p. 69, verse 512). The section dealing with the cultivation of vegetables mentions sprinkling of small quantity of cow-dung as one of the two primary activities and adds that people know that it is for the sake of promoting the fertility of the soil.

It is clear that the author of the text was familiar with the fertilising quality of the manures. They were applied after the ploughing of the field and sometimes at the time of the transplantation or later after weeding. The manure was of a rudimentary nature, in the form of the easily available cow-dung and the goat-dung. Green manure as a compost of easily available vegetation was also used.

Bhaṭṭotpala in his commentary supplements the information in the *Bṛhatsaṃhitā*, in many cases by quoting from *Kāśyapa* and the *Agnipurāṇa*. But the quotations do not introduce any new prescription of a fertilising device.

Both the *Visnudharmottarapurāṇa* and the *Agnipurāṇa* have a chapter each on *Vṛksāyurveda*.

Varāhamihira (*Bṛhatsaṃhitā*, 54.16-18) recommends a few prescriptions for curing the sterility of the trees. It can be cured by administering Kulattha, Māṣa, Mudga, sesamum and barley by sprinkling milk which has been first boiled and then cooled. For trees, creepers, thickets and plants alike it prescribes the sprinkling

of two *ādhakas* of the powder of the dung of sheep and goats, one *ādhaka* of sesamum, one *prastha*(=16 *palas* = 1/4 *ādhaka*) of *śaktu*, a *droṇa* (= 256 *palas*) of water and a *tulā* (=100 *palas*) of beef,[31] all mixed together and kept for a week (seven nights).

The *Vṛkṣāyurveda* of Surapāla gives detailed instructions about the preparation of manures and their applications[32]. These include a few general recipes with some specific ones for particular plants. In this text we have two sections, entitled, corpse-water(*kuṇapa-jala*)(verses 97-106) and nourishment (*poṣaṇa*) (verses 107-64), dealing with manures and fertilising prescriptions. It requires the pit at the root of a plant to be treated by besmearing with the paste of sesamum, oil cake and Viḍaṅga, sprinkling with the milky water or corpse-water, fumigating with ghee and remedying with oil-cake. Water, in which dung, fat, flesh, marrow, brain and blood of a hog is buried under the earth for a fortnight, is called *kuṇapa* (corpse-water) (verse 105). A second method of preparing it is to collect as much as available lymph, narrow and flesh of a horse, hog, fish, sheep, goat and other horned animals, put them in water and boil them in fire. The flesh and other things are to be properly kept in a greased vessel and to be closed. In it are to be kept powdered oil-cake of sesamum, honey, boiled beans (*māṣa*), with their soup, and ghee. There is no fixed proportion of these objects. They are to be kept in a vessel in a lukewarm place for a fortnight (verses 102-5).

The text lays down several prescriptions for the nourishment of plants, in the form of manuring formulae. It recommends that for the proper growth of a young plant a porridge made of fish, meat and sesamum should be administered cold every seventh day (verse 107). Other nourishing prescriptions are the sprinkling of juice extracted from the fruits of herbs, urine, fat, milk, corpse- water, ordure and meat, of *kunapa* mixed water in which meat and Kiṇva have been boiled (verses 112b-114), of the fat of deer and hog, honey and ghee and the juice extracted from the leaves of Nicula (verse 118); fumigation with the flowers of Siddhārtha and Arjuna mixed with the meat of deer along with Viḍaṅga, Ṛohita and Niśā (verse 116) and with the incense of plantain leaf, Siddhārtha and Śafarī fish (verse 117); besmearing with ghee, Vidanga, milk, water and honey, and fumigating with the pollen of Nalā, Kuṭha and Aja (verse 119); nourishing with the fat of python and Dhammīṇa (Hindi *Dhāmina*) (verse 120)[33] and stinging of the creepers at the root by the thorn of a Vṛścika plant, fumigating with the *śapharī* fish and ghee and nourishing with the fat of a hog and rat (verse 121).

There are some special manuring prescriptions for particular plants: for grapes (*drākṣā*) manuring the roots with the powdered ordure of cocks and nourishing with the broth of fish and meat (verse 122); for mango nourishing with the juice of ripe Ankola fruit, ghee, honey and the fat of a hog (verse 123); for palm and coconut trees (*tṛṇapādapa*) watering with the boiled juice of the flesh of a cow, hog, and porpoise and anointing with Śapharī fish and pounded sesamum (verse 124)[34] ; for coconut (*nārikela*) plastering at night with the paste made of *maireya* wine, Kinva (a drug causing fermentation), sesamum, bean, *surasava*[35], mixed with honey (*kṣaudra*), salt and Viḍaṅga (verse 125) or watering with alkaline water mixed with barley powder or with sour barley gruel (*tuṣajala*); for *pāṇyāmala*[36] nourishing with the soup (*yūṣa*) of beans (verse 125); for date tree (Kharjūrī), orange (*kamalā*

= *nāraṅga)* and bread-fruit (*lakuca*) the juice of black mustard containing barley husk and oil-cake (Piṇyaka)[37] (verse 127); for pomegranate (Dāḍimī) nourishing with the flesh of a cat, blue jay, deer, elephant and hog, plenty of fat and buffalo milk (verse 128), applying lumps of flesh of jackal (*pheru*) mixed with flesh of domestic animals (*paśu*) and inundating with copious water in which sugar has been dissolved (verse 129), plastering with turmeric, ghee, *śapharī* fish and honey (*kṣaudra*) and fumigating with the powder of *triphalā*[38] mixed with ghee (verse 130), and nourishing with non-poisonous snakes (*duṇḍubha*) boiled in milk and the broth of *śapharikā* fish (verse 131)[39] for bread-fruit tree (*panasa*) watering with the decoction of three myrobalans and decorating with husk (*palalāka*) (verse 133); for *Kola* (berry) nourishing with water mixed with liquorice (*yaṣtimadhūka*), sesamum and honey and irrigating at the root with corpse-water (*kuṇapa*) (verse 134); for Karkandhuka (jujube), bread-fruit (*Lakuca*), *badarī* (jujube), *dhātrikā* (Āmalaka) and Jambu (rose apple) trees anointing with ghee and plastering with plenty of barley mixed with paste of honey, Kṛśarā and Rodhra, fumigating with sesamum, honey and barley for twelve days and watering with diluted milk at the time of efflorescence (verse 135) and watering with an unstinted quantity of liquor (*sidhu*) (verse 136); for Bilva and Kapittha trees feeding with jaggery (*guḍa*), ghee, milk and honey (verse 137); for plantain trees (*kadalī*) dressing of the roots with old straw, dry cowdung (*karīṣa*) and ashes and sprinkling with the washings of the flesh or *kasa*[40] (verse 138); for Tinduka tree watering with the soup of rice and beans, and for Paravata trees with the juice of the leaves of Nicula (verse 139); for Matulungi (citron) trees, nourishing with the solution of sesamum oil-cakes mixed with the decoction of milk, flesh, *jhaṣa* fish, cowdung, rice and Kiṇva (a drug causing fermentation) (verse 140); for Bījapūraka (citron) nourishing with the flesh or a jackal coated with *jaggery*; for orange (Nāgaraṅgaka or Nariṅgaka) feeding with broth of meat, jaggery (*guḍa*) and milk (verse 141), watering with the infusion of Viḍaṅga, beans, sesamum, mustard and Bilva mixed with flax (*uma*), flesh of hare (*saśakamāṃsa*) and milk, and fumigating with the unguent of the flesh of hare (verse 142); for Madhuka, fumigating with abundant lumps of flesh, mixed with a little (*kalā*) of the powder of Aṅkola·bark and seasoned with the root (*siphā*) and leaves (*dala*) of Jālinī[41] (verse 143); and for Śyāmā, Kadamba and Karikesaraka (Nāgakesara), nourishing with sour gruel (*sauvīra*)[42], whey (*mastu*), curd (*dadhi*), Kola (berry) and sesamum mixed with wine (*sidhu*), *iṇḍi*, alkaline ashes (*kāca*) and corpse- water (*kuṇapa*) (verse 144).

The text recommends flowering plants to be sprinkled with the decoction of rose-apple, Pallavaka (=Aśoka), Uṣīra (the fragrant root of a plant) and Musta (grass) mixed with wine (verse 145); and Ketakī to be sprinkled with the infusion of aromatic substances like cardamom and nourished with the broth of flesh (verse 146). It goes on to recommend measures based on superstitious tradition. Ketakī is to be fed with water (from the mouth of a woman) only once (verse 147); Bakula to be sprinkled with wine from the mouth of a young woman: mango tree (Makanda) to be scratched with the top of Kuvāra as with the tip of a finger nail of a woman (verse 148); Aśoka to be kicked amorously by a young woman (verse 149); Kurabaka (a species of Amaranth) to be clasped in a sportive embrace of a coquette within her lovely creeper-like arms; and Tilaka to be merely glanced by her (verse 150).

The text mentions fertilising devices for creepers also: Mādhavī, Karavīra, and Kuraṇṭa to be sprinkled with wine (*vāruṇī*) in the evening (verse 152); Pāṭalā to be irrigated profusely with cold water mixed with milk (verse 153)[43]; Karpāsikā (cotton plant) to be washed with the flesh of fish (*jhaṣa*), Yūthī (jasmine) to be nourished with milk, sesamum, cowdung and water[44] and Sephālikā to be nourished with flesh, plenty of fish (*jhaṣa*) and flesh- broth (verse 154).

According to the text, Cirabhaṭī, Lambu, Karkaru, Trapasu and others belonging to the category of Śāka (pot-herbs) are to be fumigated with the bone and ordure of a hog on a Sunday (verse 155); Alābu (gourd) creeper to be sprinkled with the scum of rice kept overnight (verse 156); and Paṭola to be burnt (*karālita*) by straw fire in the month of Phalguna and sprinkled with a solution of oil-cake mixed with spirituous liquor (verse 157).

In another manuscript of *Vṛkṣāyurveda*, which, though drawing heavily upon Surapāla's text, is not identical with it[45], we find some additional provisions about the preparation and application of manure. It mentions the dung of goats, sheep and cows as the general manure (verse 117). The flesh of the fish mixed with Vidanga and rice is to be applied to the plants in cow-dung and urine and is also used for watering them (verse 118). The plants are to be watered with the decoction of barley, Mudga, sesamum, Masa and Kuluttha, when cooled down (verse 120). It recommends the application of powder prepared from white mustard, plantain leaves, fish and ordure of hog and cat, all in equal parts, and mixed with ghee and wine (verse 158), fumigation with the fumes of ghee mixed with earth, sprinkled with barley-water, and regular watering with diluted milk on carrion-water and plastering with Viḍaṅga and sesamum oil-cake (verse 159). It advises feeding of trees with ghee and honey in which the decoction of Aṅkola has been mixed and nourished with the fat of hog and deer as well as white mustard (verses 160-61). For creepers in general it advises piercing with the thorn of Vṛścika plant, fumigating with incense and feeding with the fat of mice and hogs (verse 156).

The text recommends the use of Aṅkola oil as an important manuring agent. The huskless seeds of Aṅkola are to be pounded and soaked seven times in sesamum oil. Then they are to be rubbed with hot water and the oil expressed by the oil-machine. Another method is to plaster two bell-metal plates with this paste and place them in the sun facing each other. The oil dripping from them is to be collected in another bell-metal vessel placed beneath them (verses 112-114).

There are detailed instructions about separate manuring ingredients for specific trees and plants: Jātī, Mallikā and Mādhavī creepers (verses 115-116), date palm, coconut (verses 122, 133-34), bread-fruit tree (verses 123, 151), mango (verses 124-26, 146), pomegranate (verses 127-29, 147-48), citron and orange (verses 130-32, 155), arecanut (verse 135), plantain (verses 136-38), jujube (verses 139-40, 154) myrobalan (verse 145), Kapittha and Bilva (verse 152), Madhūka (verse 153), Campā (verse 141), Valti (verse (142), grapevine (verse 143), Gostanī (red grape) (verse 150), Saurabha (coriander) (verse 157).

Connected with the question of the use of manure is the problem of the prevalence of the practice of rotation of crops. Each crop takes away some of the fertilising properties of the soil. Under the system of rotation of crops the succeeding crop requires elements not consumed by the preceding one, with the

result that the soil gets time to recoup the lost elements. Thus the soil maintains its properties in a cycle of crops.

We have to determine whether the cultivator resorted to the practice of leaving the field fallow after a crop to recover the lost properties or made use of the system of rotation of crops[46]. The modern practice does not encourage any high expectation about the currency of the system of rotation of crops. The Indian farmer, though familiar with many fertilising agencies, does not seem to have made much use of them. Hence, the chances of keeping land fallow after a crop increase. A passage in the *Cullavagga*, after enumerating the processes in cultivation, says that one has to do just the same the next year, and the same all over again the year after that. This suggests that one crop a year was the normal practice. But the passage is not conclusive. Possibly, in emphasising the monotonous routine of household life, it does not pay heed to the number of crops cultivated in a year. The *Yuktikalpataru* (p.6) would imply that the rotation system was not much in vogue. It says that land loses fertility from cultivation year after year; when one plot of land loses in fertility, cultivation should be done elsewhere. The *Arthaśāstra* suggests that ordinarily a cultivator raised only one crop each year. It requires the Superintendent of Agriculture (*Sītādhyakṣa*), who arranged cultivation on crown land, to decide on wet crops, winter crops or summer crops (II.24.19). Elsewhere the text advises that for replenishing the treasury during financial stringency, the offices under the Samāhartā should make the farmers sow the fields in summer (*Ibid*, V.2.8), implying thereby that ordinarily the field was not cultivated in summer. The term *khila*[47], occurring in the texts as well as epigraphic records, stands for land left fallow[48].

The pithy sayings circulating under the name of Khanā contain much traditional information which can be applied to the close of the ancient period. Khanā suggests knowledge of the system of rotation, especially when she observes 'My worthy cultivator, plant radish towards the end of the third season of the year, sow mustard towards the end of autumn, and if you mind to take money, sow maize in the following month of Caitra' (*IHQ*, VII, p. 24). There is evidence to show that people recognised two, and sometimes even a third, crop season. But two crop seasons do not necessarily establish the practice of rotation of crops, though the cultivation of three crops will imply the implementation of the system, even if rudimentary. The advancements made in the knowledge of soil, seeds and seasons would have helped the cultivator discover the benefits of rotation of crops. But, in the last analysis, much depended on the properties of the field, and the resources and the needs of the cultivator. In the inscriptions of later periods we have terms referring to fields which yielded a crop in Śarada only or in Grīṣma only, or, in some cases, both in Śarada and Grīṣma[49]; apparently the practice of rotation of crops was not common.

In the *Arthaśāstra* (II. 24.12-14) we have references to grains grouped as *pūrvavāpa*, *madhyavāpa* and *paścādvāpa*. Even if this is interpreted to refer to sowings one after another in the same field, it will not amount to the practice of rotation. Actually we have here a preferential of crops as first, middle and last.

Even in the very early stage of the domestication of plants there was a rudimentary awareness of the crop season, the proper time for sowing the few seeds known then. This knowledge grew in course of time. A *Taittirīya Saṃhitā* passage

(V.1.7.3) speaks of two crops a year. But, another passage in the same text (VII.2.10.2) says that barley ripened in summer being sown in winter, rice ripened in autumn being sown in the rains, while beans and sesamuṃ ripened in winter and the cool season, implying that there were three crops.

In modern India also there are some regional variations in crop seasons on account of the variations in the timings of rains and other seasons. There are generally speaking two main crops: the Kharif and the Rabi. In ancient India also the pattern of two crop seasons parallel to the Kharif and Rabi was the general rule. This is implied by the *Gobhila Gṛhyasūtra* (I.4.29) referring to the two harvests of rice and barley. It requires a householder to offer Āsasyabali consisting of barley from the barley harvest in the hot season till the rice harvest in autumn and that consisting of rice from the rice harvest till the barley harvest. Megasthenes points out that as there is a double rainfall in the course of each year the inhabitants of India almost always gather in two harvests annually (Majumdar, pp. 233, 252). In the *Mahābhārata* (XII. 100.1-11) the season of the two main crops of Caitra and Margasirsa is mentioned as the time for invading any kingdom. The *Bṛhatsaṃhitā* (XXXIX. 13-14) also mentions two crops *graiṣmika* and *śārada.* In some inscriptions the fields are described in terms of their being manageable to the two crop seasons of *śāradya* and *graiṣmika* (vide Note 49).

The *Arthaśāstra* evidence has been differrently interpreted. One passage (II.24.19) refers to *kaidāram*, *haimanam* and *graiṣmikam* crops. *Haimanam* is winter crops and *graismikam* is summer crops. *Kaidāram*[50], according to Shamasastry and Kangle, refers to wet crops. Some scholars take *pūrvavāpa*, *madhyavāpa* and *paścādvāpa* in another passage (AS, II. 24.12-14) as referring to three seasons[51], but Kangle correctly takes them to refer to the rating of crops in priority[52]. S.P. Raychaudhuri (Raychaudhuri p.81), following Shamasastry's translation of II. 24.10, says that the *Arthaśāstra* evinces acquaintance with there harvests. But, the reading refers to rain distributing wind and sunshine properly and creating three periods for the drying of cow-dung cakes (Kangle, II, p. 172 f.n. 9), and not to three sowings[53]. Though the relevance of these passages is doubtful, another passage in the text does not leave any doubt about three crop seasons being actually followed, at least in some parts. In its advice about the seasons for marching on an expedition it mentions three crops: monsoon crops, winter crops and spring crops. It says that a king should march against the enemy on an expedition in Mārgaśīrsa for destroying his monsoon crops and winter sowing, in Caitra for destroying his winter crops and sprinig sowings, and in Jyeṣṭha for destroying spring crops and monsoon sowings (*AS.* IX. 1.34-36).

The pattern of three crop seasons is indicated by some other sources also. Pāṇini mentions *āśvayujaka*, *graiṣma* or *graiṣmaka* and *vasanta* or *vāsantaka* named after the season of sowing. Hemachandra mentions four seasons of sowing, Śarad, Hemanta, Grīṣma and Aśvayujī, and four of reaping, Agrahāyaṇa, Vasanta, Śarad and Śiśira (*Abhi.C.* VI.3. 116-118).

Irrigation

Water is essential for the growth of crops. Rain water is the first and the foremost source of water supply. But, in many cases it is either insufficient or irregular or not available at the proper time. Rain water has to be supplemented by man-made devices of supplying water. Even in the case of other natural sources of water, such as rivers, streams, lakes and ponds, human effort is required to carry or direct water to the field. Thus, irrigation falls into two clear categories, natural and artificial.

Scholars have made several, sometimes conflicting, assessment about the nature and volume of rainfall in the Harappan period, hence we cannot determine precisely the extent to which agricultural prosperity of the Harappans was due to this source of irrigation. In the absence of any definitive evidence about artificial irrigation the fact of the predominance of winter crops in the Harappan economy has been taken to be based on 'flood irrigation farming' using moisture and silt provided by river floods.

The ruined Gabbarbands (*lit.* stone dams) in south Baluchistan placed by Lambrick between c.3000-1000 B.C., have been related by Hargreaves with the Nal culture. Though no traces of gabbarbands are reported from Harappan sites, it has been suggested that the Harappans also used such dams for storing water for irrigational purposes.

At Lothal a trapezoid reservoir measuring on an average 214 × 36 meters has been excavated. It is surrounded by an embankment wall of kiln-fired bricks, the shorter arm on the north having a gap for the inlet of water with another gap in the south providing for spillway. Following S.R. Rao (pp. 70-73) the excavator, it is taken to be a dock, but Leshnik (vide Possehl 1979; *AA* 1970, pp. 911-22) and Junghans (Possehl 1979, p.210) argue for its having been an irrigational tank. It had a capacity of about 500 cubit meters with provision for refilling. In any case, this shows that the Harappans had a developed tank technology. The Great Bath at Mohenjodaro is an illustration of it, but we do not have any indication to confirm its use for irrigation. This holds good for wells that have been exposed at a number of habitational sites of the Harappan culture and are the earliest excavated stained wells having burnt brick lining.

The wells at Harappan sites show a developed technology. Those at Allahdino (Baluchistan) with their small diameter, location at the top of the site, and the divided drains with movable sluice block suggest well water irrigation (Possehl, 1979, p. 210). Some of the water lifting devices associated with the Harappan wells can be determined. Sign of friction by the ropes on the sides imply drawing of water by a rope with pots attached to it. It has been suggested that the water-lifting device of shaduf was in use. The picture of a man using shaduf at a well is embedded on a piece of lime at Mohenjodaro. The ring-stones recovered from Mohenjodaro and Lothal are explained as counter-weights for the arm of a shaduf. Mackay suggests that the scored pottery from Mohenjodaro was attached to a wheel, which was managed by an endless rope, for drawing water for irrigation (Marshall 1931, I, p.318)[54].

The earliest archaeological evidence about an irrigational device is available from Inamgaon, a Chalcolithic site. It is in the form of an embankment and a channel

belonging to the early Jorwe period (c. 1300 B.C.). It is 240 m. × 2.25 m. on the right bank of the Ghod river and is built of stone rubbles set in mud in its basal courses. Parallel to it is a channel running north-west measuring 118m × 4m and 3.5m deep. It was dug through hard 'marrum' down to rock and prevented much loss of seepage. The huge basaltic outcrop on the left bank of the river checked the flow of flood water. The channel served not only for flood diversion but also for storing water (54000 cubic feet) of which excess could be diverted by gravity flow into the fields to the west and in winter when the water level sunk pot irrigation was resorted to (Misra and Bellwood, 1985, p. 388).

The Vedic literature testifies to the realisation of the importance of rain. The high position of Indra in the Vedic pantheon and the allegoric references to his killing Vṛtra and releasing the cows glorify the phenomenon of rains. In ancient texts we have numerous references to the benefits of rains, to the eager waiting of it, and to the joy and festivities on its coming.

The Vedic literature refers to sacrifices being resorted to for bringing rains. Yāska (*Nirukta*, II.11) names a group of hymns in the *Ṛgveda* (X.98) as *Varṣakāmasūkta* or hymns recited at a sacrifice performed to bring about rain. The belief in the efficacy of sacrifice to cause rains is recorded in the *Gītā* (III.14) and the *Manusmṛti* (III. 76). R. Gangopadhyaya (p.112) goes too far in asserting that this belief had 'a substantial basis' as 'famines were few and far between in the time of the Ṛgveda when Indra worship was greatly in vogue'.

The natural phenomenon accompanying rains was carefully observed and analysed. The Purāṇas describe the formation of clouds and their different types with their characteristics (*Vā.Pu* LI. 28-46; *Br. Pu.* II 22.23.50; CXXV 11-35, *see also* Sen S.C.). The *Arthaśāstra* shows an early development of the knowledge of clouds when it mentions (II.24.9) three types of clouds which continually rain for seven days, eighty which pour minute drops and sixty which appear with a sunshine.

The process of the formation of clouds and of rainfall was described in terms of an embryo and delivery. The pregnancy lasts six months and a half. It begins in autumn-winter, but there was a wide difference of opinion about the actual period of the formation of the rain-embryo. According to some it occurred after the bright half of Kārttika, but the majority view placed it from the first day of the bright half of Mārgaśirṣa (*Bṛhatsaṃhitā* XXI. 5.6). The period of the delivery of the rainfall was determined accordingly (*ibid.* 9-12). Varāhamihira records auspicious marks for the nourishment of the rain foetus, symptoms in different months favouring their health,and also indications of miscarriage (*ibid.*, 13-28).

Another aspect of study concerned planets and other connected phenomena for determining the nature, volume and timing of rains. This was closely associated with the development of astronomy to which significant contributions were made by the requirements of the Vedic cult of sacrifices and later by the Jainas and various schools of astronomy, including Greek and Roman. The application of astronomical knowledge to agricultural work was noticed by Megasthenes (Fragment I, p. 41; Majumdar p. 237) who says that the philosophers of India,when gathered together at the beginning of the year, forewarn the assembled multitudes about droughts and wet weather and also about propitious winds.

Rain gauging was prevalent in India even before Pāṇini (III. 4.32) who provides for terms referring to measures of rainfall. The *Arthaśāstra* (II. 5.7) describes the rain-gauge as a basin with a mouth one *aratni* (= 24 *aṅgulas*) in width. According to the *Bṛhatsaṃhitā* (XXIII.2) the raingauge is to be one *hasta* or cubit (18 inches) in diameter. When filled to the brim it indicates 50 *palas* or 1 *āḍhaka* of rainfall. Parāśara (as quoted by Bhaṭṭotpala on *Bṛh. S.* XXI.32) mentions a raingauge 20 *aṅgulas* (15 inches) in depth and 8 *aṅgulas* (6 inches) in diameter. When filled to capacity, it indicates one *āḍhaka* rainfall. Parāśara equates four *āḍhakas* to one *droṇa*. He mentions another method of measuring rainfall. Water spread over one *dhaṇus* (=4 cubits) of land indicates one *droṇa* of rainfall. But, in the *Kṛṣi-Parāśara* (verse 26) the measurement of one *āḍhaka* of rainfall differs radically. It says that an *āḍhaka* measure of water is a hundred *yojanas* wide and thirty *yojanas* deep.

The *Meghamālā* defines *drona* as a continuous rain for seven nights together (Shastri,p.298).Varāhamihira in his *Samāsasaṃhitā* (quoted by Bhaṭṭotpala on *Bṛh.S.*, XXIII.2) refers to the system of measurement of rainfall as prevalent in Magadha, which seems to have been recognised as the standard one.

Kauṭilya (*AS*, II. 24.7-8) says that a forecast of rainfall can be made by observing the position, motion and pregnancy of Jupiter (Bṛhaspati), the rise, setting and motion of Venus (Śukra), and the natural or unnatural aspect of the sun.

Ṛtuvijñāna or climatology developed along with astronomy. The *Bṛhatsaṃhitā*, the most standard work of this type, has many chapters dealing with several aspects of the subject. Varāhamihira himself refers to some earlier authorities, but their writings are not available in their original form. Quotations from these reproduced by Bhaṭṭotpala in his commentary confirm their existence. The early medieval period witnessed the composition of several works on weather-forecasting. Of these only the *Gurusaṃhitā* has been critically edited. Some others, such as the *Mayuracitraka* and the *Meghamālā* are yet to be printed. These books contain weather-maxims similar to those current in many provincial languages. Though their scientific validity has not been investigated, Indian peasants depend on them for the rich practical wisdom stored in them. They present a strange mix-up of astronomical considerations and natural phenomena. Though the indications appear to be superstitious in some cases, they were evidently based on careful observation spread over a long period.

The *Kṛṣi-Parāśara* shows how astronomical knowledge was used for forecasting rainfall in the interest of cultivation. One could have a knowledge of rainfall on the basis of the planets which happen to be the lord and minister of the year (verses 11-22). It lays down indications for determining the nature of rainfall in various months from Pauṣa to Śrāvaṇa on the basis of the planets and natural phenomena (verses 30-64). The movement of planets from one zodiac to another is also taken to indicate rainfall and draught (verses 71-79). The text mentions certain natural phenomena and the behaviour of human beings, birds, animals etc. as indicating immediate rainfall (verses 65-70).

The importance of irrigation for agriculture was well realised. The *Arthaśāstra* (VII.14.21) refers to the irrigational works (*setubandha*) as the source of crops. Bṛhaspati (XIV. 23) mentions the suitability of a field for irrigation as one of the qualities conducive to a rich crop. The prosperity of a kingdom was often attributed

to its irrigational work. (*MB*. II. 5:77; Rām II.100. 44-45; Kirata,I.17). Megasthenes correlates the fertility of the Indian soil with the fact that a greater part of it was under irrigation from the water of the rivers (McCrindle, Frag.I, XI; Majumdar, pp. 232, 252). The vogue for irrigational works is indicated by the terms *devamātṛka* and *adevamātṛka* or *nāḍīmātṛka* (*Amara*, II.1.12; *MB* II. 5.77, II.51.11) referring to the classification of regions on the basis of their depending on rains or using irrigational work.

Varāhamihra in his *Bṛhatsaṃhitā* devotes a full chapter (No. 53) to the subject of water-divining. It is termed as *dakārgala*, of which the more explicit form is *udakārgala*. Varāhamihira admits that he presented in Āryā verses the *Dakārgala* composed by Sārasvata and narrates in Vṛtta verses another written by Manu (verse 99). Though both these texts are not available in their original form, quotations from them are reproduced by Bhaṭṭotpala.

Varāhamihira speaks of eight underground arteries of water, four flowing in the four cardinal points and four in the intermediate directions with a ninth which shoots upward (verses 3-6). He takes the presence of certain trees and ant-hills in different directions of specified trees as indicating underneath water at a waterless place (*ambu-rahita*).

He mentions the depth at which water will be available, the nature of the water, the direction in which it flows, the type of stones and soil to be met at different levels and fish, frogs, rats, snakes and tortoise to be noticed (verses 6-85). The depth at which water is indicated for a desert land (*marudeśa*) is not applicable to a *jāṅgala* land (with little water). In the case of *anupa* land (with much water), if certain specified trees are found in ant-hills, then water will be at a distance of three persons length (*puruṣas*), in *jāṅgala* land at a distance of five *puruṣas* and in *maru* land at a distance of seven *puruṣas* (verses 86-89). There are general indications of the presence of water in the form of colour and nature of soil, availability of vegetation on them, and the presence of anthills and insects without home (verses 90-96).

On the basis of the *Dakārgala* of Manu, Varāhamihira says that where trees, shrubs and creepers have glossy and thick foliage and have milky juice, there an underneath water artery exists. He names certain objects, grasses and trees as indications of water underneath. Water is also found at the bottom of a hill which is placed on another hill (verses 100-2). Varāhamihira mentions the nature of the soil, its formation and colour as indicating that the water will be sweet or salty (verses 103-4). Water is far from the surface where certain trees grow and where trees, shrubs and creepers have sparse leaves and are dry (verse 105). A soil of the colour of sun, fire, ash, camel and ass is devoid of water. If the Karīra trees have red sprouts and have milky juice, water will be available under the rock (verse 106).

Varāhamihira distinguishes rocks on the basis of their colour for the easy availability or remoteness of water (verses 107-10). For breaking rocks, which cannot be easily split, he records ways and means on the authority of Manu (verses 111-17).

The subject of water-divining was not developed further by any later scholar. We have, however, the *Viśvavallabha* of Cakrapāṇi[55] which deals with the subject

of location of underground water in chapter 1. It is clearly based on the *Bṛhtsaṃhitā* of Varāhamihira from which many verses have been borrowed. We do find some elaboration and new information about the indicators of underneath water. There is some change in the scheme of the chapter with verses 32, 33 and 34 presented as separate sections dealing with water respectively in arid areas, marshy lands, and mountainous country. In the absence of the texts of other authorities mentioned by him, we cannot determine the extent to which Cakrapāṇi added details from his own experience.

Varāhamihira makes it clear that the treatment of the subject of *dakargala* was for the digging of wells (*Bṛhatsaṃhitā* 53. 77, 121- 123). He considers wells situated in the Āgneya (east-south), Nairṛta (south-west) and Vāyavya (west-north) directions to be inauspicious and recommends their placement in the other five directions (verses 97-98). Likewise, he recommends a *vāpī* (reservoir) which is east-west long and not south-north; the latter is destroyed by the water agitated by winds. In such a reservoir the flow of water is to be enclosed by strong wood, stones or baked bricks and the embankments are to be hardened by being crushed by elephants, horses and other animals (verse 118). At one place there was to be an outlet gate with a well made bed, the channel lined with stones and a panel, without aperture, fixed in a frame and covered by grit heaped against it (verse 120).

The *Arthaśāstra* (II.1.20) mentions two types of *setus* (embankments), the *sahodaka* referring to tanks, wells etc., which have a natural supply of water, and the *āhāryodaka*, which store water in reservoirs. Discussing the comparative benefits from the different types of irrigational works, Kauṭilya remarks that one which is of perennial water is better than that which is fed with water drawn from other sources, and of works with perennial water that which can irrigate an extensive area is better (*AS*. VII. 12.4.5).

Nārada (XI.18) classifies irrigational works into two: *kheya* (canal) or that which is dug into the soil in order to drain off excessive water, and *bandhya* (embankment) or that which is constructed to prevent water from flowing away. The *Bṛhatkalpasūtra Bhāṣya* (123a) (Motichand, p.165) records the regional peculiarities of irrigation devices. Certain regions (like Lāṭa) depended solely upon rains, others (like Sindhu) used the rivers, some others (like Dravida country) relied upon reservoirs, some (like Uttarāpatha) used wells, at some places (like Banāsa) seeds were sown after the floods had receded, while in others (like Kananadvīpa) paddy crop was cultivated on boats.

Lakṣmīdhara lauds the merit of constructing a special type of reservoir called *dvārībandha*. It was made by damming a mountain spring and thus forming a high level reservoir useful for irrigation (*Kṛt*. pp. 292. 286 and Introd. pp. 116-17).

Suyya, a minister under King Avantivarman of Kashmir, accomplished a remarkable work of engineering skill. He dammed the river Vitasta (Jhelum). He built stone embankments for seven *yojanas* and temporary stone dams at all threatened points and succeeded in shifting the junction of the river with the Sindhu to its existing position (*Rāj*, V. 84-121).

The Vedic literature implies a clear knowledge of wells and water being drawn from them (*RV*. I.116.9). *RV*. X.101.5, as translated by Griffith, reads: "Arrange

the buckets in their place; securely fasten on the straps. We will pour forth the well that hath a copious stream, fair-flowing well that never fails." Verse 7 of this hymn (*ṚV*. X. 101.7) has been translated by S.A. Dange (p.11) more effectively than by Griffith: "Sprinkle out this well, that is drinkable for men, which is endowed with the wooden containers fitted with stone wheel and wherein the reservoir is provided with a top guard." Dange, however, envisages an ordinary well and does not suggest that the buckets were joined to form a chain. Ghurye (p. 226) sees in the passage a reference to the modern Rahat, but does not use the name. This, in any case, could have been noria and not the Persian wheel, because of the absence of a reference to the operation of the device by the bulls and to the gearing system (Gopal 1980, pp. 153-154). The significance of another passage (*ṚV*. X. 102.11) has not been precisely analysed. The term *kucakra* occurring in it is taken by Dange (p.11) to refer to a water-wheel, a device of circular jars. It is not unlikely that it signifies a wheel with earthen jars attached to it (Gopal, 1980, pp. 154-159).

Most of the P.G. Ware sites are situated on the river banks. The location gave them the advantage of inundation of the fields and also provided the facility of overflow irrigation through shallow canals. At the P.G. Ware site of Jakhera (Etah, U.P) the exposed moat like water channel (Sahi, II, p. 104) was possibly used for irrigation also. In the *Ṛgveda* (V. 4.1,7) Ṛbhus are the craftsmen who led forth the rivers. Some passages suggest embankments obstructing rivers. Indra broke them to set the rivers free (*ṚV*. III. 3.7).

Rivers were an important source of water for irrigating the fields. In a *Jātaka* story (V. 291) the Śākyas and the Koliyas are represented as being very keen in asserting their rights to use the waters of the Rohiṇī for irrigating their fields.

Irrigational activity was promoted by the establishment of larger kingdoms and the increase in the sphere of state activities.The concept of state's responsibility for irrigational work issued directly from the theory connecting failure of rains and the occurrence of natural calamities with some grave lapse on the part of the king and requiring him to provide help and redressal against calamities.

The *Arthaśāstra* (II. 1.20-22, 39) requires the king to construct reservoir filled with water either perennial or drawn from some other sources. He is to provide sites, roads, timber and other necessary materials to people undertaking the cooperative construction of irrigational and other works. He is advised to maintain those constructed earlier and to provide for new ones. The actual implementation of this advice is confirmed by the fact that even in the outlying province of Gujarat Puṣyagupta, the governor of Candragupta, the Maurya king, constructed a reservoir 240 cubits long, just as many broad and 72 cubits deep, and later on it was restored and adorned with conduits. We have epigraphic evidence to trace the history of this tank from the times of Candragupta Maurya and Aśoka to Rudradāman, the Śaka Kṣatrapa, and Skandagupta and to note how it was carefully maintained on account of its usefulness.

The testimony of Megasthenes about the control of river irrigation and the sluices is corroborated by the *Arthaśāstra* (III. 9.27-31, 38). It provides for ensuring that the water of the tank is let out only at its sluice-gate and not at any other place, the flow of water from the sluice-gate is not obstructed, and the natural flow of water from a higher to a lower tank is not stopped.

The lexicons list special terms for different types of reservoirs (*Abhi. R.* 675-77; *Vaij*, p. 154). The *Aparājitapṛccha* (pp. 18-85) gives an elaborate classification of reservoirs: ten categories of wells, two of small wells (*kūpikās*), four of *vāpīs*, four of *kuṇḍas* and eighteen of tanks. The *Mānasollāsa* (II, p. 137, verse 1613) names a miśra tank as one which every year receives fresh water channels and is bound up with embankments.

The construction of tanks is evidenced by archaeological exavation. Among the earliest belonging to the historical period are those from Rupar and Ujjain (*IAR*,1954-55, p.9 ;1957-58, p.36) which are dated roughly to the phase 600-200 B.C. They were large tanks. At Rupar the tank embankment is made of a brick wall and a brick-built inlet provides for the coming of rain-water.

The tank at Ujjain is made of burnt bricks. The walls of a tank of Dharmarajika at Taxila are made of the rubble masonry with a plaster coating to prevent water from percolating (Marshall 1951, I, p. 247).

At Sringaverpur (Allahabad) excavations have exposed a rectangular tank (*IAR*, 1978-79, p.58) made of bricks measuring 41.5 to 44 × 27.5 to 28.5 × 6 to 7 cm. It is assigned to the beginning of the Christian era. Its measured length is about 100m but its ends have not been determined. The sides are retained by three successive walls of baked bricks with battered back against the natural soil. The tank was fed by the water of the Ganga brought through a channel 2m wide. The mouth of the tank made of baked bricks was shaped like an arc of a circle. The bricks at the base of the channel were set in a stepped fashion so that the base and side walls were not eroded by the gushing water. The floor of the tank near the mouth was paved with unusually large bricks 64 × 12 cm.

The tank was divided into two parts interconnected with a channel paved with large-sized bricks measuring 64 × 48 × 12 cm. Cascating over a flight of steps, water entered the inner and larger part of the tank. There was staircase of five steps, each having four courses of bricks, which connected the mud platform of the retaining wall with the brick platform projecting from the lowest retaining wall. The lowest retaining wall turns outwards at this point, which marks the beginning of the inner part of the tank. Another platform with 17 courses intact is seen on the other side of the channel. The inner part of the tank with south- west orientation is both bigger and deeper than the outer one. The length of this part of the tank remains to be ascertained.

A number of inscriptions belonging to the early centuries of the Christian era refer to the pious work of digging tanks. Excavations also support it. In many cases this activity is connected with foreign people entering India from the north-west. Possibly the experience of irrigational work in Central Asia contributed to the promotion of tank-digging. Excavations show that in this period the practice of offering votive tanks had become popular. The Smṛti literature shows that the digging of wells and tanks was included in the list of works of high religious merit designated as *iṣṭāpūrta*.

It was mostly in South India that huge tanks of great engineering skill were constructed. The Pallavas carried out a lavish programme of irrigational work throughout their kingdom. The technical skill attained in the construction of tanks

at that time is clear from the fact that even now they serve the purpose for which they were made. The Tenneri tank near Kanchipuram, the Mahendrataṭāka in Mahendravadi in North Arcot,the Parameśvaraṭatāka, the Vīrameghataṭāka in Uttaramerur, the Kaveripakkam tank and the tank at Mamandur are associated with Pallava kings; some of them are mentioned in the ancient epigraphs (*ANRASI*, 1903-4, pp. 203 - 4; *IC*, XII, p. 74; Gopal, 1989, pp. 283-286).

The mathematical texts show the actual relevance of the functioning of the reservoirs. They refer to the regulation of fountains (*nirjharas*) for filling a *vāpī*, the time taken to fill it when a given number of channels (*pranalis*) are operated, and for water to flow out of it through a device (*yantra*) (Li. p.39, no.95; GSS. VII. 32-33; IV. 28-39).

The *Kāśyapīyakṛṣisūkti* is the only known Sanskrit text which deals with practical details about irrigational facilities for fields. It emphasises the need for the construction of a water reservoir near a village or town. It is to be constructed near a hill or on a table-land with a big lake and, in the case of a plain on a firm-land, near a perennial spring. It is to be provided with a causeway and channels and sluices for filling and emptying it. It may be fed by a mountain rivulet, a big lake, a forest brook or a big river and should be provided with a suitable contrivance for the distribution of water. It is to be provided with a very strong and big culvert and several small channels branching out of it for the easy outflow of water.

In the *Rāmāyaṇa* (II.80.1, 11-12) we find a reference to the *yantrakas* who made provisions for water. When the road from Ayodhyā to Sṛṅgaverapura was being constructed, they dug wells and tanks where there was scarcity of water. At places they built small dikes which later gained the shape of tanks. A very interesting confirmation of it is available from the excavations at Sringaverapur (near Allahabad) where a tank has been exposed.

The Pali text *Dhammapāda* (verses 80,145) refers to *nettikas* who forced water to go where it would not go by itself. They were specialised builders of canals and aqueducts.

The term *odyamtrika* occurring in the Nasik Cave inscription (Luders no.1, 1,137) is translated as hydraulic engineers. But the precise nature of the work done by them and the device they used are not known.

Patañjali (Keilhorn, I. 11) vividly describes a well-digger, who, in excavating, is covered with dust particles, but the hardship suffered is more than compensated when he uses the water, because the resulting prosperity (*abhyudaya*) leads to welfare (*yoga*) of many type. But, here we do not get any details about the technological aspect of digging a well.

The *Kāśyapīyakṛṣisūkti* recommends irrigation from ponds, tanks and, more particularly, from wells. After ascertaining the presence of water by the examination of the soil by an expert of the rules of water-divining and by observing the strata of the earth from the direction of the roots of trees a well or a pond is to be dug. At first a big pit is to be dug, oblong, square or circular in shape. Digging is to be continued till water appears. Then, for making the foundation strong the base is built in latticed masonry of burnt bricks and sometimes in stone-slabs. Bricks masonry is to be gradually raised over the base. The walls are to be made

of bricks laid in lime mortar. Steps are also to be provided wherever necessary. The structure above ground is to be made of stone-slabs in which an opening is to be kept towards the east or west according to the situation of site.

Archaeology reveals wells in different parts of India which belong to various periods. A comparative study of their technical details, shape, measurement including depth, lining of the walls, shape and size of bricks, and the device for drawing water and their flow to the fields, will throw welcome light on this aspect of irrigational technology. To exemplify we may refer to the well at Kumrahar datable to c. A.D. 300-450 (Altekar and Misra, p.31). It is brick-paved and has a diameter of 2.25 ft. There are 104 courses going to the subsoil water. For sealing it a special kind of bricks were used which were 10 inches long and 2 inches thick, the breadth being 7 inches at the inner edge and 9 inches at the outer one. The wells of the Gupta period exposed by the excavations at Bangarh (*ANRASI*, 1903-4, pp 4-9) are made of bricks which are broader on one side. The big well excavated at Rajghat has walls measuring 2.7 metres, the inner diameter being 2.35 metres. The inner surface is plastered with lime water (*IAR*, 1965-66, pp 54-55; 1966-67, p. 44).

Large scale canal work in India is evidenced only from the early Muslim times. The absence of a regular term for a canal in Sanskrit would create the impression that canals were not much in vogue in ancient India (Laping 1978, pp. 4-5). The term *praṇālī* occurs in the Hathigumpha inscription of Kharavela. This is the earliest epigraphic reference to an aquaduct dug out (*oghāṭita*) by king Nanda (possibly Mahāpadma) three hundred years earlier. But *praṇālī* may refer to a narrow water course and not to a large canal (Sircar 1966, p. 256). In the *Arthaśāstra* (III. 8.21,23) also the term implies a channel, a drain, a small water-course, a trench for sanitation or rain-water.

But, the presence of canals is inferred from passages referring to water reservoirs which could be maintained only through a continuous supply from a perennial source[56]. A more direct reference can be seen in *khātapravṛttim* (*AŚ*.III.9.35), one of the three types of irrigation works, which means dug out to channelise. Likewise, the irrigation work (*setu*) of the type made by digging (*khanya*), as mentioned by the *Nāradasmṛti* were for diverting water (*toyapravartana*) and imply canals. A Ṛgvedic passage (III.33.4) may imply canals carrying water of rivers. Parallel to it is the *Agnipurāṇa* (272.4) reference to arms of rivers made to run into tanks.

But, archaeological testimony does not leave any doubt about the actual digging of canals in ancient India. The excavations at Kumrahar (Bihar) have revealed a canal assignable to the Mauryan period. It measures 45 ft. ×0 ft. deep. It possibly ran between the Son and the Ganga (*IAR*. 1954-55, p.19). Megasthenes testifies that under Candragupta Maurya canals were a regular part of irrigational activity. It was on such a large scale that it required the appointment of a special class of officers who "superintend the rivers, measure the land, as is done in Egypt, and inspect the closed canals from which the water is distributed into the conduits" (McCrindle, Frag, XXXIV; Majumdar, p. 268).

The excavations at Besnagar (Vidisa, M.P.) have revealed an old irrigation canal in use by 165 B.C. which could have been Mauryan or pre-Mauryan in origin. Its surviving walls measure 7′ × 195′4" with a height of 5′6". The canal possibly

extended upto the river Bes (*ANRASI*, 1914-15, pp. 69-71). It has been suggested that it was an inundation canal and served the purpose of storing water.

The pioneering work in this respect was done by Karikāla I, a Cola King, belonging to the close of the first century A.D. He erected embankments to control the river Kaveri. For utilising the water of the river Karikāla cut a number of canals so that water could reach the fields (Aiyangar, PTS; pp. 360 ff; Aiyangar SK. pp. 93 ff; Sastri, pp. 26 ff; Dikshitar, pp. 71ff).

The *Kāśyapīyakṛṣisūkti* says that in the absence of the facility of a water-reservoir a canal is to be provided. Such a canal is of four kinds, as it is fed from a river, a lake, a reservoir, or mountain slopes (i.e. a mountain rill). The feeding source of the canal is to be on a level higher than the region to be irrigated. An embrasure is to be made in it. In constructing the canal its bed is to be laid. The breadth of the canal is to be four, five, six, seven or ten *hastas*. Its height should be proportionate to its bed and its depth adjusted everywhere to the volume of its flow. Places with terrene faults, which cause the water to disappear either by absorption or desiccation or are covered with saltpetre, are to be avoided. At places two or three canals are to be dug according to requirement. The canals are to be made to fall gradually into a lake or pond. Where there is no such water- reservoir, the canal is to terminate into the fields, but, in such places, only small culverts are recommended.

The *Arthaśāstra* (II.24.18) refers to a number of devices for lifting water for irrigation. These are *hastaprāvartimam*, *skandhaprāvartimam*, *srotoyantra-pravartimam* and *nadīsarastaṭākakū—podghatam*. The precise meaning of these expressions has not been determined. Kangle translates them as meaning 'set in motion by the hand', 'set in motion by shoulders', 'set flowing in channels by a mechanism' and 'lifted from rivers, lakes, tanks and wells.' It may be pointed out that *prāvartimam* here does not qualify a mechanism or device set in motion. It refers to the diversion of water or its being brought from one's own irrigation work (*svasetu*). Kangle takes *hastaprāvartimam* as referring to the carrying of water in pitchers. Laping suggests that it may refer to any one of the devices - the swing - basket, the shadoof, dhenkli or tath, the picota, the spoon irrigation lever and bucket being emptied into higher basin. *Skandhaprāvartimaṁ* is interpreted by Laping as referring to the raising of water by the help of draught animals, as in the case of *mot*. Meyer takes *srotoyantra* to refer to the Persian wheel. Laping suggests that it may refer to a more primitive water wheel, one turned with the feet, but prefers to take it to denote 'some device for the regulation of the outflow, probably a sort weir or spillway'. Kangle's rendering, though in effect brining out the nature of the irrigational method, does not emphasise the device referred to in the original expression. It is to be rendered better as 'diverted (regulated or brought) by the device of sluices'. In this case the water flows to the fields through channels. In the fourth expression the term *udghātam* reminds us of *oghāṭitam* in the Hathigumpha inscription. Kangle's rendering of it as 'lifted from' does not indicate the nature of the device. It may refer to the digging out of channels. This does not involve any complicated or expensive device for manipulating or regulating the flow of water from the original source of reservoirs. It meant the natural flow of water through a

channel from a source (river, lake, tank or well) at a higher level to a field at a lower level[57].

The *Cullavagga* (Nalanda ed., p.212, line 1) records the names of three water-lifting devices which were permitted to the monks by the Buddha: *tulam*, *karakaṭakam* and *cakkavṭṭakam*. In drawing water many earthen pitchers (*bhajana*) are broken, hence the Buddha permitted the monks to use three kinds of vessels (*varaka*) made of iron, wood and leather. Buddhaghoṣa (fifth century) in his commentary *Samantapasādikā* adds information about these devices. *Tulā* is the pulley for lifting water, resembling the balance of a merchant[58]. *Karakaṭaka* is the device for drawing water by hand or by yoking bulls and with the help of long straps or ropes. *Cakkavaṭṭaka* is the *arahaṭṭaghaṭiyantra*. The leather vessel attached to a *tulā* or a *karakaṭaka* was known as *cammakhaṇḍa*.

Hemacandra gives seven Deśī terms for the contrivance *tulāyantra* for raising water from a well. We cannot be sure if all these refer to the same appliance or signified several slightly differing devices (Gopal, 1989, pp. 289-90).

Scholars often use the expression Persian wheel for a water- drawing device in ancient India (Sharma. 1967, p 41; Nath 1970, p. 84), though reservations have been expressed by a few (Needham, IV(2), pp. *361*-62; Basham 3rd ed. p.194). Irfan Habib explains the device as being novia and holds that the Persian wheel proper, an innovation of the Arabs, was introduced in India in the 13th-14th centuries (*PIHS*, 1969, PP. 152-53).

A panel from Mandor (near Jodhpur, Rajasthan), assigned to the eleventh century, depicts a Persian wheel (Gopal, 1980, pp. 114-68). It has a wheel with a chain of terracotta buckets. The wheel is presented in profile and the gearing mechanism would be on the other side. Hence it need not be a noria.

A wheel device for drawing water from well is evidenced in the *Ṛgveda*, but its nature cannot be determined precisely. We have to allow margin for regional variations and for improvement and developments, even at a very slow pace. We find several terms, which, in some cases, were not used in their strict sense. *Araghatta* was the term for the full device. *Ghaṭīyantra* referred to the main part consisting of the wheel and the pitchers. The rotation of the cycle of pitchers is often referred to metaphorically in a number of texts in a philosophical context of the cycle of birth and death (*Kuv*. pp. 227, 277; *Upa, Pr.* pp.16, 418, 723; *Chana. U* comm. II. 15.5; *Br. Su.* II.2.19). The texts mention only those parts of the device which are relevant to their context, hence the negative argument of the absence of reference cannot be carried too far. The functioning of the device is also mentioned in the *Pañcatantra* stories (*Tan*, pp. 142-43; *Pañc*. pp. 231-44), writings of Bāṇa (*Hṣa*. II, p 42; *Kād*. pp. 85, 322), *Mṛcchakaṭikā* (X.59) and *Gathasaptasati* (V. 90). The earliest epigraphic reference to the device is traced in the Mandasore inscription of Yasodharman (A.D. 352). The *Upamitibhāvaprapañcakathā* of Siddharṣī (A.D. 906) gives a detailed account of the various parts of the device and its functioning.

The text refers to sluices (*nirvahani*), channels, fields, seeds and a sower and adds that sown seeds, irrigated (*sikta*) by the *araghaṭṭa*, fructify into crop. It speaks of reservoirs (*pānāntika*) attached to the well for the purposes of irrigation

(*secanārtham*). The device is associated with a well so deep that its bottom in not visible. The text makes a clear distinction between the *araghaṭṭa*, the *kūpa* and the *ghaṭīyantra*. The *araghaṭṭa* is described as fitted with all the materials or parts. The text refers to four cultivators (*karṣaka*) also called *sarathins* (drivers of bullocks). The sixteen bullocks are speedy and agitated with vigour. The text speaks of two big gourds (*tumbadvaya*) only, but the number is dictated by the requirements of Jain philosophy and implies many pitchers. The term *araka* (spoke of the wheel) and the reference to the device revolving constantly (*satatabhrama*) indicate that the device is not ordinary *pura* or *purahaṭa*.

A critical analysis shows that the device in ancient sources was similar to noria in some cases, but in others it was nearer to the Persian wheel. In the *Upamitibhavāprapañcakathā* the chain of pots is mentioned as mounted on the wheel and as quite separate from it; the pots are not attached to the rim of the wheel. There is no clear reference to a gear system in the device, but neither is there a reference to the rotation of the wheel through manual labour. The text implies that there were many other parts of the device (*sarvasāmagrīsamyukta*), besides those specifically mentioned. The references to the device revolving continuously and through its own action also suit a Persian wheel.

According to D. Sharma, the Persian wheel was known before the beginning of the Christian era. R. Nath holds that it was used as early as the age of the Imperial Guptas. Metrodorus, a Hellenised Persian, who came to India in the fourth century, found that water wheels were regarded in India as a new invention (Needham, IV(2), p. 369). In the absence of specific details we cannot identify the device referred to by Metrodorus. The combined testimony of the *Pañcatantra*, *Gāthāsaptaśati*, *Mṛcchakaṭikā*, *Samantapasādikā* and the Mandasore inscription would imply that the device had been in use before the times of Hāla and Viṣṇuśarman. The reference in *Cullavagga* suggests a date several centuries before the Christian era.

The use of the term *cakkavaṭṭakam* in the *Cullavagga* and the first occurrence of the name *arahaṭṭaghaṭīyantra* in the *Samantapasādikā* suggest that a specific name for the device took centuries to establish. For the introduction of the *araghaṭṭa* device a date in the 2nd-3rd century may not be much beyond the mark. Amarasiṃha, the lexicographer, does not record technical terms associated with the device, suggesting that they had not come into regular usage. A critical analysis of these terms in the lexicons (Gopal, Aspects, pp 142-49) later than the *Amarakośa* shows how these terms gradually came into general acceptance.

Epigraphic references suggest that the *araghaṭṭas* came into a larger use in the early medieval period (Gopal, Econ. p.290). The device involved expenses which were not within the means of any ordinary cultivator. The *Upamitibhavāprapañcakathā* mentions the landlord, his cultivators, supervisors and female labourers in connection with the device. The complicated device required specialists to operate them. The *Tantrākhyāyikā* (pp. 142-43) has a story relating to a person who operated an *araghaṭṭa*. Epigraphic evidence also confirms it (*Akh.* p. 146, v.12).,

The *Samarāṅgaṇasūtradhāra* (I,pp. 178-79, verses 109-14) describes four water-machines (*vāriyantra*) to bring water down (*pāta*), to raise it first and then

to bring it down (*ucchrayāsamapāta*), to bring it down and then to raise it (*pātasamocchrāya*), and to raise it (*ucchrāya*). But all this was for the recreation of the rich class. It is highly improbable that they were commonly used for irrigation.

The *Kāśyapīyakṛṣisūkti* (verses 167-69) gives an account of the devices for lifting water from a well and for using it for irrigating the fields. For raising water a place for fixing the machine is to be made on stone-slabs on the brink of the well, and for the outflow of water a small conduit is to be made on a hard surface near the edge of the well. Of the different kinds of machines for raising water the one drawn by bullocks yoked with strong chains is the best, that by the elephant with its trunk is the mediocre, and the one by human labour is the inferiormost. Water on lower levels in steadily raised to the surface of the wells etc. by the revolution of the water-raising machine. Water is then carried to the fields by means of small channels.

Irrigation of fields through channels carrying water is evidenced by the Vedic literature. *Khanitrima* (vide Macdonell and Keith) in it refers to a water channel for irrigation. There are references to channels for irrigating fields (*ṚV*. X. 19.4), to the digging of channels for a forward course (*ibid*, X. 75), and to hymns sung when cutting a channel (*AV*. III. 13)[59]. *Kulyā* is the term for a channel for irrigation (*Amara*, I.10.34). The term occurs in the Vedic literature. Following Sāyaṇa modern scholars have taken it to refer to an artificial stream or water-course falling into a reservoir (vide Macdonell and Keith, I, p. 214). A stock example in Vedānta (*Vedāntaparibhāṣā*, p.23) speaks of the water of a reservoir issuing from sluices and entering the fields flowing through a *kulyā*. A passage in the *Mahāvagga* (VIII.12.1-2), as explained by Buddhaghoṣa, refers to fields in Magadha being irrigated by rectangular and curvilinear channels and ridges. The legend of Āruni, the pupil of Dhaumya, lying down to stop a breach in the water-course of a certain field (*Mbh*.I.3) indicates the nature of the irrigation channels.

The system of using water for irrigation through channels is indicated in the *Arthaśāstra* (III.9.27) which mentions the flow of water from the reservoir or source (*ādhāra*), through the outflow or a channel (*parivāha*), to the field being watered (*kedāra*).

Notes

1. *Sahi, 1981, p 47 suggests, on the basis of anchylosis of hook-joints in cattle bones from Hallur, the use of plough in south India in neolithic culture in the second millennium B.C.*
2. *Mackay, Pl. CVIII.3 - records chipped chart objects measuring 12.5 × 5.35 × 3 inches.*
3. *Frakfort reports a ploughed field in the excavations of the Harappan site of Shortughai (Eastern Bacteria) (see Lal and Gupta, p. 303).*

4. *A terrracotta object from Mohenjodaro (now at Prince of Wales Museum, Bombay) measuring 7 × 19.7 cm (Mackay, Pl. CVIII.3) could also have been a model of a plough.*

5. *They are hard and lasting. In some parts of Central India ploughs are made of Khair without an iron share - Dhavalikar in Puratattva, No.8, p 44. Cosmos (Christian Topography XI, p. 358) mention ploughshares made of the leather of rhinoceros. It is not supported by any other evidence, but cannot be ruled out as being improbable.*

6. *On this basis Malti Shende, p. 240 postulates the use of plough by the Harappans.*

7. *Sharma R.S. p.111 doubts if horses were yoked to ploughs. Pliny refers to ploughing done by elephants. See Majumdar R.C. p. 342.*

8. *Agnihotri, p. 254 adds that the driver stands on the log.*

9. *Kings ploughing with golden ploughs - MB, III. 255.28; III. 256.2 red hot or flaming ploughshares - Sik.S. pp. 77,87; Balarāma fighting with a plough - MB.IX. 37. 38; clefting heads of elephants and horses with a plough Kat. K. p. 62; gift of pañcalāṅgalakam - Mat. Pu. 274.9; 283; ordeal of ploughshare - Bṛh. P. X. 28-29.*

10. *Ray, p. 134 holds that wooden ploughshares might have been used during the NBP period. Ray also infers from a few iron hoes from some urban sites that hoe cultivation was the general vogue, but they could as well have been household tools.*

11. *Hemacandra, Abhidhānacintāmaṇi, VII.2. 135 gives several explanations of it which indicate deep ploughing.*

12. *The reading Prthurāma is enigmatic.*

13. *Raychaudhuri, pp 10-11 adopts faulty reading. Verses 35 and 41-42 given here do not appear in the critical edition prepared by Rahul Peter Das.*

14. *Verse 57 prescribes a special treatment of the seed of Ervāru (or Airvāru) which cannot be identified.*

15. *Bhaṭṭotpala takes saktu to refer to a separate item along with vṛihicūrna, masacurna and tilacurna.*

16. *Bhaṭṭotpala paraphrases tāla as tālā. Tāla is a measure of length. Bhaṭṭotpala explains it as referring to a measure of time.*

17. *EI, V, - no. 5 (I and II) vrithipitakavapam, vrīhidaśapras- thavapam; EI, II, no. 5 (I) - vrīhiptavāpam ; EI, V, no.16 (A) and EI, XII, no.12 - dvādaśakhaṇḍikakodravabījapari- māṇam, EI, X, no.11 - vāpagatyā koraḍe sandhadroṇasapta- parikalita.*

18. *Randhawa, pp. 485-86 quotes Parāśara for the full operation of transplantation. But this is not found in the Kṛṣiparāśara.*

19. *Raychaudhuri, p. 103 splits it into Rājakośa and Āmra.*

20. *ītayaḥ smṛtaḥ.*

21. *Raychaudhuri, pp. 94-98 gives translation of verses 185-222 and 165-84, from this text without any justification for reversing the order. Earlier, on pp. 85-86 he reproduces translation of verses 87-105 from a Vṛkṣāyurveda, but without giving details about the location of the manuscript and its author Evidently, this is also based on Surapālas text.*

22. *Raychaudhuri, p.95 renders it as diluted milk apparently on the basis of the reading kṣīrāmbu.*

23. *Raychaudhuri p.99: 'according to scientific works', appparently reading śāstraeṇa for śastreṇa.*

24. *Raychaudhuri, pp. 85-88, 96-97 is confusing about the original sources and their translation.*

25. *Raychaudhuri, p.87 gives the English translation, but does not mention the original source.*

26. *Raychaudhuri, pp. 96-97 mentions it as occurring after verse 222. But the printed text does not have it.*

27. *Raychaudhuri, p.87 does not mention the source.*

28. *Majumdar and Banerji, p. 83, f.n 2 point out that "all the names are not intelligible, and, therefore, not mentioned here".*

29. *Verses 645-48. Raychaudhuri, p.73 mentions these as verses 599-601.*

30. *Raychaudhuri, p. 605, verse 404 - "has been carefully dressed with the dung of cows or goats or with (decayed) vegetable matter".*

31. *Raychaudhuri, p.99 translates gomāṃsatulayā as "beef equal in weight".*

32. *Raychaudhuri, p.99 gives translation of verses from the Vṛkṣāyurveda of Surapāla on manures and manuring in two sets, pp. 48-52 (verses 101-7, 112b-14, 118-26, 128-57, 159) and pp. 52-55 (verses 82-85, 112-61) without indicating their relationship, which is confusing. See Gopal, 1980, pp. 104-8 where the passages in the first set are reproduced as being from the Vṛkṣāyurveda of Surapāla. The text has now been critically edited by Rahul Peter Das (Stuttgart, 1988). The second set of verses belong to it. The first set is derived from an anonymous manuscript entitled Vṛkṣāyurveda. Rahul Peter Das, pp. 19-52 has shown that many authors drew on Surapāla's Vṛkṣāyurveda.*

33. *Raychaudhuri, p.49 does not recognise the word Dhammina.*

34. *Raychaudhuri, p.49 oca (?) in place of uttha, meaning 'arising from'.*

35. *Beer or spirituous liquor made of unripe corn; Raychaudhuri p.49 - Murā liquor.*

36. *Pānīyāmalaka (Flacourtia Cataphracta).*

37. *It also means saffron and asafoetida.*

38. *Three myrobalans taken collectively are Harītakī (Hiraḍā), Vibhītaka (Bahaḍā) and Āmalaka (Āmbalakaṭī).*

39. *Verse 132 refers to superstitious practices of hanging the skull of a blue jay (cāṣa) on a pomegranate tree and the neck of a broken jar on top of a hog-plum (Āmrāta) tree.*

40. *A species of rodent animal.*

41. *Jālinī = Kośātakī (Luffa acutangula Roxb).*

42. *It also means the jujube tree.*

43. *For the first part Raychaudhuri, p.51 reads 'sprinkled (?) with mouthfuls of kitakalapa (?)'. This is on account of a misreading of the original kīlā-kalāpa-kavalaiḥ kalitā. For Pāṭalā also the translation 'with water mixed with kitakalapa' is not supported by the text.*

44. *Raychaudhuri, p.51 takes 'the solution of dung in water' to be prescribed for Saptacchada.*

45. *Raychaudhuri, pp. 52-55 mentions both the texts as the Vṛkṣāyurveda of Surapāla - ibid, pp. 48-52.*

46. *Aiyangar, p.78 for rotation of crops. Bandyopadhyaya, p.129 suggests that the practice of leaving fields fallow had been completely dispensed with.*

47. *A track of land not under cultivation for a year is termed ardhakhila by Nārada, XI.26.*

48. *Breloer takes vāpatirikta in Arthaśāstra, II. 24.16 to mean 'fallow land', but Kangle, part II, p. 172 f.n. 16 explains it as referring to 'land which the sītādhyaksa has not managed'.*

49. *Dabok Inscription dated A.D. 813 (EI. XX, no.13)-śāradyagraiṣmikakṣetra, śāradyakṣetra and graiṣmikakṣetra*

50. *Ganapati Sastri (Arthaśāstra, 1. p.287) does not take it to be a third crop, but explains it as meaning sowing in a field of rice etc. Johnston, JRAS, 1929, p.26 proposes the reading kedare meaning 'on wet land'.*

51. *Raychaudhuri. pp. 81-82, pūrvavāpa and paścādvāpa are taken to correspond with Kharīf and Rabi crops respectively.*

52. *The Kauṭilīya Arthaśāstra, II, p. 172, f.n. 12 - 'in the alternative, this may imply sowings one after another in the same field; but that does not appear very likely'.*

53. *Ganapati Sastri reads karṣakān for kariṣān, but this cannot mean ploughing or sowing.*

54. *Marshall, 1931, p. 318 opposed the suggestion.*

55. *The text has not been published. It is available in the form of manuscript (Mss. Collection No. 195) in the Vallabha Vaisnava Matha Library, Nathdwar, Rajasthan. Raychaudhuri pp. 6-9, 24-33, 55-58, 88-94 gives transatation of long passages from Chapters 1,2,6-8. The text, which claims to have been composed by Cakrapāṇi, a devotee of Rāma and belonging to a Brāhmaṇa family of Mathurā, as desired by the king, is evidently a late work, though it draws upon earlier texts. On its own admission, it borrows from Hemādri and Sārṅgadharapaddhati and hence could not have been earlier then the fifteenth century.*

56. *Laping AS II. 3.3 - water reservoirs in a fort; II. 3.4 moats; II. 1.3 - manipulated rivers to be established to serve as boundary marks. Also Manu, VIII. 252. Laping speculates that the cultural contact with Mesopotamia could have introduced the technology of building large canals.*

57. *Elsewhere we had suggested that the third and the fourth expressions may refer respectively to a water-wheel device similar to a Persian wheel, Gopal,1980, pp.155-56.*

58. *Popularly known as ḍhekulī it operates with the help of a weight or big stone at one end of a pole with a vessel or water bag attached to the other end.*

59. *The relationship between a canal and river is compared to that between a calf and a river.*

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Fermentation Technology

MIRA ROY

Fermentation (from Latin 'Fermentum', to boil) is a particular method of digesting of relected substances that leads to chemical transformation of organic substances into simpler compounds by the action of ferment. Generally fermentation quickly sets in substances of high sugar-content. Hence fermentation technology started in different parts of the old world with sweet-substances, may it be vegetable or animal product. In Egypt honey was utilized first for preparation of intoxicating drink by fermentation. In India *Soma* juice, a sweet substance formed the first article of fermentation by the Vedic Aryan.

On all probability the art of fermentation was invented from observation of some changes in several fruit juices and other food substances stayed over for a day or two or three or more. The technique of fermentation, as history evince, appeared almost simultaneously with settled agriculture during Neolithic period. At the outset the technique came to be recognized as 'self- generated', a fact proved by the two terms indicating fermented product from honey and date in Egyptian terminology (Forbes, 1965, pp.61-65).

Coming to India, as its earliest literally record, the *Ṛgveda* (c.1500 B.C.) shows fermentation paced its first step in connection with the preparation of Soma-juice, a sweet potion for divine oblation. There also occurs another drink of fermented product called *surā* (beer, a product of cereal and honey).

Besides spirituous acetic fermentation (*Sandhānāmla*) was known in India from early period. From 1st century A.D. onwards these two fermented products are found to have also been used as aid to different medicinal compositions, surgical performances (spirituous liquor served the purpose of anesthesia) and in numerous chemical and alchemical operations.

Milk products, like, curd (*dadhi*) requiring fermentation for changing of milk into such coagulated substance, was a very popular food article even in the *Ṛgveda*. The technique of curdling milk occurs in a number of texts connected with the *Yajurveda*.

Fermentation in India principally centred round the preparation of spirituous drink. Terminology associated with fermentation are :-

(i) *āsuta* (begetting a new form),

(ii) *abhiṣuta* (extraction, may indicate extraction from fermentated mash),

(iii) *parisrut* ('foaming', 'fermenting', i.e. the state of fermenting) and

(iv) *Sandhāna* (complete absorption of ferment with fermenting material).

The expressions, however have a direct approach to 'distillation', the post fermentation operation in the manufacture of liquor. All the terms therefore, signify 'brewing', predominated by act of fermentation. Excepting the last one all the other terms are found to occur in Vedic literature.

So far the technology concerning fermentation is found to have been based on four functionaries: These comprise:

(a) base material (*yoni*),

(b) ferment or yeast (*kiṇva, nagnahu*), alternatively, auxiliary (*sambhāra*), imparting flavour and good taste to liquor in addition to fermenting,

(c) heating or digesting, and

(d) fermenting vessels.

How this technology in India evolved from sacrificial altar to chemical laboratory, i.e. a period from c. 1500 B.C. to 15th- 16th centuries A.D. is to be now summed up in three major phases of development :

(i) Vedic period (c.1500 B.C.- 600 B.C),

(ii) Post-Vedic period (600 B.C. - 1st century A.D.) and

(iii) Period of scientific and technical literature (c.1st century A.D. onwards).

Paucity of written document debars us from extending the antiquity of art of fermentation beyond Vedic period.

I. Vedic Period

Soma and *Surā*, are the two soft quoted drinks in vedic India. *Ṛgveda*, the early text of the Aryan, clearly states *Soma* as a divine potion and *Sura* as a human drink. The *Yajurveda* however deifies *Surā* and uplifts it in the status of *Soma*.

Fermentation evident in the Ṛgveda

Spirituous Fermentation

Soma, the exhilarating plant product by itself, usually prepared by squeezing its juice. The post operations suggest fermentation as evident in the following statements:

a) Admixture of thick juice of *Soma* with barley powder (ṚV.IX. 68.4). Here clear indication of fermentation with barley is noticed.

b) 'Fifteenth day old highly intoxicating Soma'. This 'Fifteenth day' on all probability refers to 'kept in fermented vāṭ for 15 days (ṚV.X.27.2)

c) The *Ṛgveda* (IX.82:1) in another place specifically mentions 'Soma being treated is red". Here the root verb 'asavi' from Root √*Su*, indicates fermentation. What is interesting, in Chinese language '√*Su*' means fermentation. The *Surā* in Sanskrit is *Sula* in Chinese, meaning 'rice beer' (a fermented product from rice) (Mahdihassan, 1981, p.227).

Fermentation Technique

The techniques revealed in the above passages comprise,

(i) fermentation with barley (possibly *yavakiṇva* or barley as ferment of later period), and

(ii) fermentation carried on even for fifteen days.

Base Material: *Soma* juice-the other components of *Soma* juice were *dadhi* (curd) and *surā* (beer). Later Vedic texts, i.e. *Śrauta Sūtras* describe technique of preparation of these two substances.

Fermentation vessel: droṇī (wooden bucket).

Yajurvedic evidence to Fermentation

Spirituous Fermentation

The *Śukla Yajurveda* (*Vāj. S.* XIX. 13-15; 82-83) on two occasions describe preparations of two intoxicating drinks, viz. *Surā* and *Parisrut*. Surā is beer, stated to have been prepared from germinated paddy, germinated barley, parched rice (*laja*) fermented in honey with the aid of ferment or yeast (*nagnahu*).

The technique involved there was deposition of the entire substance in a pitcher (*kumbhī*) for three nights. This particular fermented product was called *māsara*. The liquid extracted from fermented mass was purified by means of sieve (*kārotara*).

The *Kātyāyana Śrauta sūtra* (XV, 9.28-30; XIX, 1-2) gives a detail account of preparation of *Surā*. In this preparation boiled rice or boiled barley used to have been mixed with ferment (*nagnahu*) and also with *māsara* (i.e. above fermented product as in the later period some acetous fermentation underwent a mixture with some fermented product).The entire mass was kept in a jar and the jar was deposited in a pit for three nights. During this period cow's milk and powdered parched rice were poured in the pot. (*Fig.1*)

The technicalities thus revealed in these two preparations are:

I. Māsara

a) substances for fermentation: germinated paddy and barley, parched rice.

b) Medium: Honey.

c) Application of ferment.

d) Sealing up in a pitcher for three nights.

II. Surā

a) Substances: as above, the additional was milk.

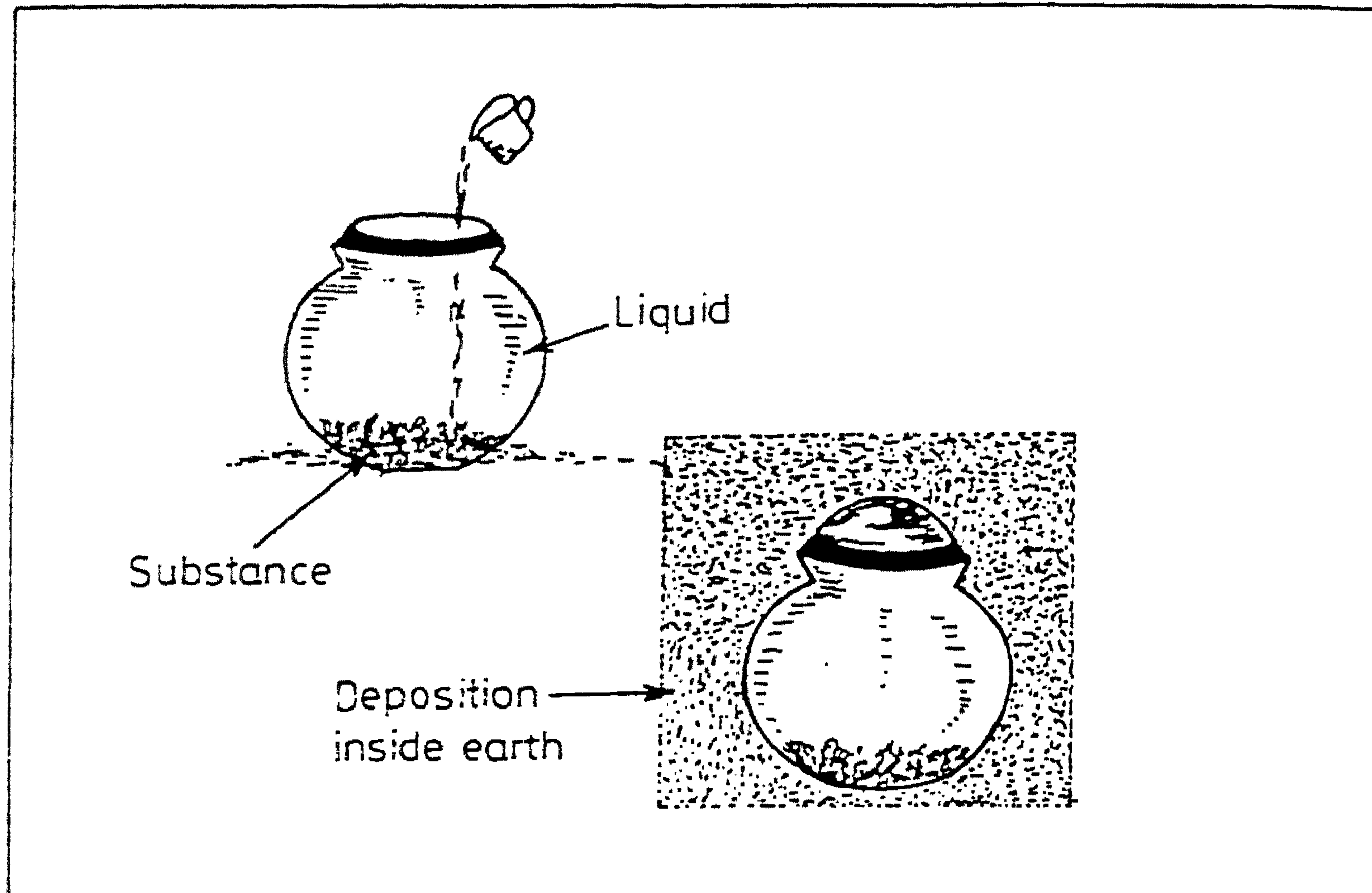


Fig. 1 Vedic Technique of Fermentation

b) Use of *māsara* as well as the ferment.

c) Deposition of the pot in a pit.

d) Pouring of milk and powdered parched rice during fermentation.

III. Parisrut

Parisrut (meaning 'foaming, fermenting') another fermented drink, called *surā* (beer) is found to occur in the *Śukla- Yajurveda* (*Vāj.S* II . 34, XIX. 15, XX.19, XXI.29). According to the commentator it was either fermented flower juice, possibly *Bassia latifolia* (II.34, *vide* Mahīdhara's commentary) or fermented germinated paddy (*Śat. Br. V.* 1.2.14, commentary by Harisvāmin).

Coagulation of milk

Dairy product involving fermentation is evident from the *Ṛgveda*. The produce is *dadhi* (curd), essential sacrificial offering to Gods and an ingredient for the preparation of *Soma* juice.

The *Taittirīya Saṃhitā* (II.5.3.5) describes the technique and substances for curdling of milk by curd, by whey, by rice-grains, by pieces of Soma-creeper, by *pūtika* (*Basela alba*) and by bark of *palāśa* (*Butea frondosa*). Curdling was performed on previous night. Fresh hot milk was used for coagulation.

II. Post-Vedic Period

The post-vedic period introduces us with some new developments in fermentation technology. Excepting ferments, auxiliaries and large number of plants in the preparation of different varieties of liquor, adaption of new technicalities in fermentation is presumed from two new preparations: vinegar (*amla*) and liquor from bread (*puvasurā*). Fermented liquor came to be known as *āsāvya* (*Aṣṭd*, iii.1. 126) and *kṛta-surā* (*Rām. Sund*, 11.12; 22-23). Industrialization of *Surā* as opposed to sacrificial preparation of the same took place. This highlighted the following development in the field of brewing, fermentation wherein formed the primary operation.

I. (i) Base materials became numerous with the utilization of a large variety of plant substances (*AŚ.* II.25) *Vip*.S.ii.19; *Rām.Ayo*.114.20) inclusive of: (a) rice and barley among cereals; (b) grape, palm, mango, wood-apple, *dhātrī* (*Emblic myrobalan*) and sugar-cane, among fruits; (c) flower like *Jāti* (Jasmine), madhuka (*Bassia latifolia*), *dhātaki* (Grislea tomentosa), (d) barks of *meṣaśṛṅgī* (*Gymnema sylvestra*), *putraka* (*Artemisa*), etc.

(ii) Treaçle (*AS.* II.25) in addition to honey became very popular fermenting substance. Pre-eminence of both the substances, particularly molasses went unabating in the next period when a new era began with employment of fermented produces in therapeutic measures and chemical practices.

II. (i) *Ferment* (*Kiṇva, bījabandha, surā-bīja*): Composition consisted of one *droṇa* (about 12 litres) pulp of *māṣa* bean, raw or boiled, rice flour, one-third of a *droṇa* admixed with one *karṣa* (about 23 gms.) each of *moraṭa* (roots of sugar-cane) and other substances. Substances and ratio of preparation occur in Kauṭilya's *Arthaśāstra* and thus liquor with high percentage of ferment was called *bījottara* (AS.II.25)

(ii) *Auxiliary* (*sambhāra*) (*AS.* II.25): A compound served two-fold purposes, fermenting and adding flavour and taste to the liquor. The ingredients of this preparation consisted of cinnamon, *Plumbago zeylanica*, *Emblia ribes* and *gaja-pippalī* (Elephant pepper plant) each one *karṣa* of weight along with two *karṣas*, each of betel nut, liquorice, *Cyperus rotundus* and *Symplacos racemosa*. This auxiliary was employed for the preparation of *āsava*. Kauṭilya recommends bark and fruit of *putraka* as added in *Sambhāra* for effecting fermentation. It was a substitute for *kiṇva* (ferment). *Sambhārikī* a special liquor was prepared with high percentage of *sambhāra*.

III. Technicalities Associated with Preparation of

(a) *beer* (*surā*) from cake and

(b) *vinegar* (*amla*).

(a) *Surā* from cake (*puvc surā*). The Buddhist text in course of discussion about five kinds of Surā, refers to *surā* from cakes (*VP.* IV.110). The technicalities involved in this preparation is not discussed. This can be substantiated from ancient practice of preparation of 'beer-bread' prevailing in Near Eastern countries. Germinated cereals and hulled fruit soaked in water (added salt or lye) dried, ground

and given the shape of a cake which was called bread. Brewing was performed by soaking it in water and subjected to fermentation with the aid of yeast (Forbes 1965, pp. 65-67).

(b) *Amla* (Vinegar, acetic acid): Kauṭilya refers to two types of *amla*-preparation, derived from fruit-juice and *phalāmla* and from molasses (*amla-sidhu*). Fermentation in this preparation was made for a longer period so that product became sour. Kauṭilya states these as home-made products (*AŚ*.II.25)

General Principle of Preparation of Different Substances

The ferment generally constituted 1:2 or 1:5 ratio of the weight of the principal substance. Kautilya formulated proportions of different substances for a particular variety of intoxicating drink.

Names of *Surā*(beer) (*AŚ*.II.25, *Rām*, *Bāla*, 53.2; *Sund*. 2.22-23)

Medaka (spiced rice beer),

Prasannā (spiced barley or wheat bear),

Āsava (sugar cane beer),

Āriṣṭa (medical tincture),

Maireya (fermented liquor from treacle, decoction of bark of mesasrngi, and three myrobalans)

Madhu (grape beer).

These were some of the popular drinks during this period.

The varieties of fermented liquors envisage knowledge about different fermentation processes developed during this period. On all probability the techniques came from outside either through foreigner's visit or from trade-contact.

III.Period of Scientific and Technical Literature

With the advancement of medical science and with the progress of chemical and alchemical practices there occurred development also in fermentation technicalities. A number of digesting devices appeared.

These include (a) depositing the fermenting vessel inside earth, sometimes with arrangement of horse dung surrounding the vessel (*Śār.S*, *Madhya*. XI.72; *Āin*, p.73); (b) placing in heaps of grains (*SS*.Ci x.6; *C.Saṃ*, *Grahaṇī* Cikitsā. VS.31-32) (c) exposure to sun(*Śār.S Madhya*, XI 19); (d) fumigation of the pot with desired substances (*RP*. XV. 251-53). (*Fig.2*)

Apart from *Kiṇva* or yeast several plant substances were marked as '*sandhāna-oṣadhi* (herbs effecting fermentation, *RHr*. iii.4). Some new recipes for ferment were formulated. One such recipe is laid down in the *Rasopaniṣat* (*RP*. XV 251-253). "The best ones among the five classes of bulbous plants with latex pounded along with grains of rice, of *Kodrava* (Paspalum scrobiculatum), and products of plant *madana* (emetic nut), pasted with whey of buffalo or cow-milk and kept closed in a bowl and another such is arranged over it. The (closed) vessel is then placed over exposure to sun. The acid residue thus obtained is *kiṇva (yeast)*".

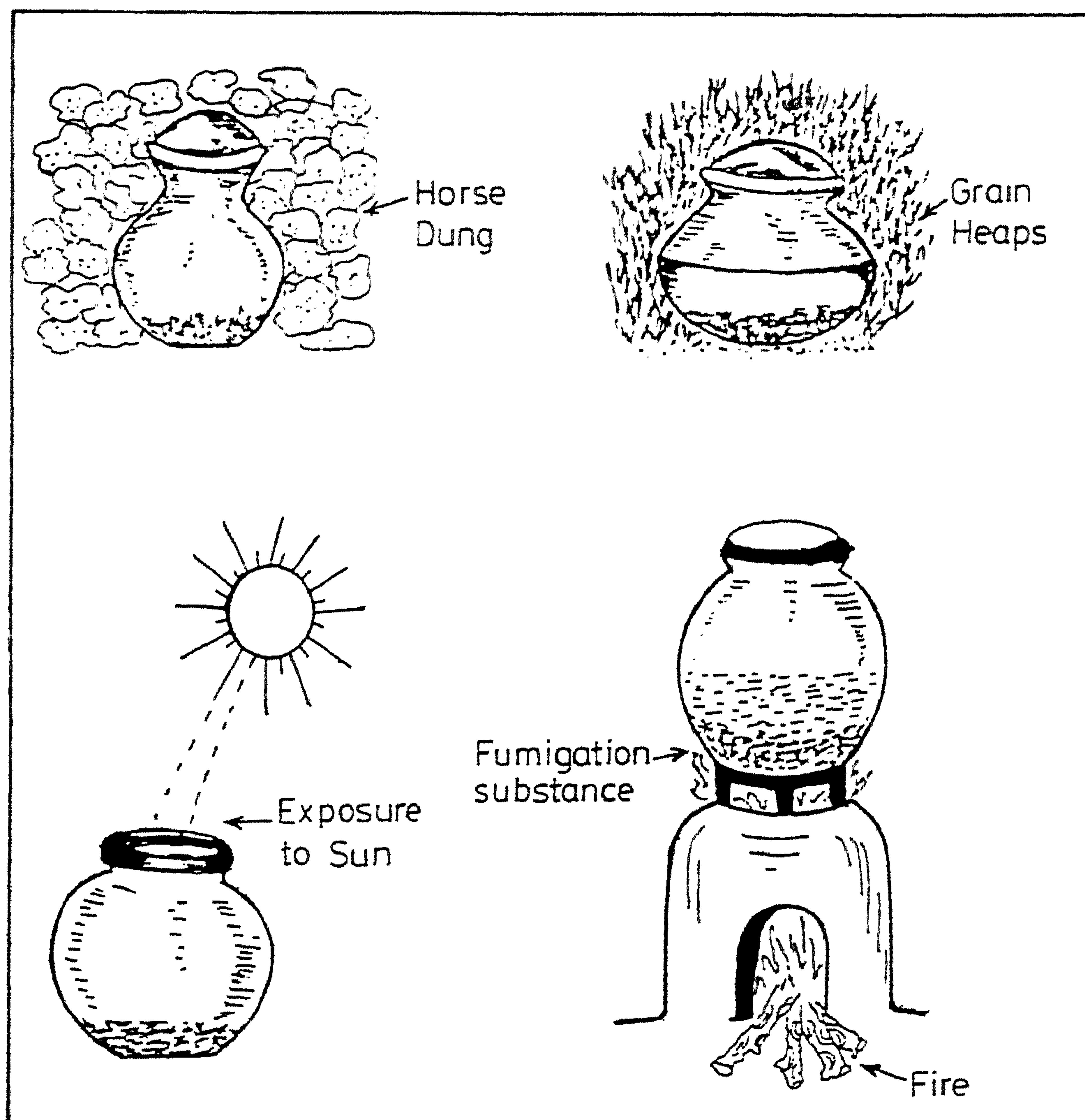


Fig.2 Four Digesting Devices

The manifold uses of spirituous fermentation and acetous fermentation started. For different purposes difference in substances and in operational methods are notable. Base-material was called *yoni* (*SS. Sū.* 45. 214). The fermented produces were specified as *tri-yoni, dvi-yoni* etc. in cases where materials were not confined in one substance but two or three. The juicy product obtained from fermented mash was called *Jāta-rasa*. (*SS. Sū* 44.30; 34; 45. 203). On several occasion the liquid extract from boiled substances were used as medium of fermentation (*SS.Sū.*44.42-43).

Ariṣṭa, āsava and *surā*, the three spirituous fermentations were potent medicinal drugs. Likewise - *āranāla, cukra, dhānyāmla, kāñjika, sauvīraka, śukta, tuṣāmbu* and the *yavāmbu*, the various acetic acids, apart from their medicinal uses (*SS. Sū* 44.28-40; *Utt.* 58.15-16), were considered essential substance for washing of metals and minerals and for various mercurial operations (*RHṛ.* ii.3.4, 14; *Rnv.* x. 39-41; vii.124; xi.61-65). Even they formed an important article in hair-dye.

Techniques Involved in These Two Preparations

I. Spirituous fermentation (Surā-Kalpa) (SS. Ci.10.6-8).

Āriṣṭa : Powder of selected drugs (having medicinal value as well as fermenting properties), water (half of the weight of powder), iron-powder and treacle ($28^{1}/_{2}$ of the weight of water), placed in an earthen vessel purified before and coated inside with a mixture of honey, clarified butter and powdered *pippalī* (long-pepper plant, *Piper longum*) and containing clarified butter. The vessel tightly sealed was dipped for fermentation in a mass of barley for seven nights.

Āsava : A mixture of three parts of cold alkaline water, prepared from the ash of either *palāśa* (*Butea frondosa*), or sesamum, and two parts of inspissitated juice of sugar-cane was subjected to fermentation like *ariṣṭa*.

Surā: In this preparation fermentation of decoction of desirable drugs admixed with ferment (*kiṇva*) was performed in the same way that followed in case of *āriṣṭa* or *āsava*.

Special Surā for Purgation (SS. Sū. 44. 29-34):

(i) Three parts of decoction of prescribed plant substances and two parts of sugar boiled over fire, made cool and the solution kept in an earthen jar for upwards of a month in such a manner so that half of this period in the winter and the other half anterior or posterior of winter, was subjected to fermentation.

Similar preparations made with alkaline water, cow's urine and spirituous or distilled liquors, are also prescribed by Suśruta.

(ii) *Māṣakalāya* (*Phaseolus Roxburghii*) soaked in a decoction of purgative roots was dried in Sun. Some winter rice was also washed in the decoction (and dried) and powdered coarse. Pulse and rice mixed together was made into balls, dried and powdered very fine. The powder heated along with the decoction of purgative drugs, pressed hard and made paste. Three parts of this paste and one part of *kiṇva* (herbs used for as forment) admixed with suitable quantity of decoction was subjected to fermentation in an earthen jar.

This preparation finds similarity with 'beer-bread' of the Egyptian, Sumerian and Accadians.

Apart from these medicated liquors, a number of other fermented liquors with variations in basic material and with their respective medical valued are found to occur both in *Caraka* and in *Suśruta-Saṃhitās*.

A List of fermenting substances with base materials is given in *Table 1*

II Acetic fermentation.

The acetic acid substances included in acid-group by the alchemists are given in Table 2.

The history of fermentation technology in India from antiquity to the medieval period highlights some aspects of this art which are particular to India and also enlightens some bearing similarity with those prevailing in more or less contemporary world. These relate to:

Table 1 - Fermenting substances

	Name of drink	Base Material	Reference
i)	*Ākṣiki*	Chebulic myrobalan and rice	*CS. Sū.27*(Madya Varga) *SS. Sū.45*(Madya Varga)
ii)	*Jogala*	Unboiled rice	*Ibid.*
iii)	*Jambu*	Molasses with juice of the fruit of *jambu, Eugania jambolana.*	*SS. Sū.* 45
iv)	*Khārjura*	Date	*SS. Sū.* 45
v)	*Madhūlaka* or *Madhūlika*	*Mahua, Bassia latifolia* (mountain variety also)	CS. Ibid. SS. Ibid.
vi)	*Mādhvika*	Honey	*SS. Ibid*
vii)	*Maireya*	Rice or barley or wheat flour, molasses, honey (three base materials).	*SS. Ibid*
viii)	*Mṛdauka Mṛdvika* or *Madhvāsava*	Grapes.	*SS Ibid*
ix)	*Pakvarasa* or *Pakvaraṣa Sidhu*	Thickened cane juice and dark- brown crude sugar	*SS Ibid*
x)	Yavasurā	Ferment of barley (*yavakiṇva*)	*SS. Sū. Ibid*

Table 2 — Acetic fermentation (*Sandhanamla*)

Name of sour liquid	Base material	*Technicalities*			
		Ferment medium	Digesting device	Vessel	Reference
Aranala	Husked uncooked wheat or any cereal group		Heat (solar) Duration - oneweek		RHṛ.III.4. (vide its comm. by Caturbhuja Miśra
Cukra	Bulbous root root, fruits, etc. of desired plants	Medium - Drinks alcohol sweet juice whey	Deposition in heap of pady Duration - Three nights	Purified earthen vessel	*Sār. Sas. Madhya khaṇḍa*, XI, 7-9. *Caraka-saṃgrha Grahaṇī, cikitsā,* SI. 31. *Caraka, Sū. 15.* 7. *Amarakoṣa. Vaiśya varga,*
Dhānyāmla	Unhusked, raw paddy powdered no associated with any other substances.	Ferment same as with *Kāñjika.* Medium- Water			*Caraka, Sū.15.7.Amarakośa Vaiśya varga,* SL. 39. Rasārṇava, VII. 22; X. 40.

Contd.

(Contd. Table 2)

Name of sour liquid	Base material	*Technicalities* Ferment medium	Digesting device	Vessel	Reference
Kāñjika, also called *Amla kāñjika*	a) Boiled rice b) Boiled inferior *māṣa* c) Boiled millet or barley also	The entire body inclusive of roots of plants in pieces Names of plants : *bhṛṅgarāja*, *muṇḍi* *Viṣṇukrāntā*, *Punarnavā* *mīnākṣi*, *sarpākṣi*, *sahadevī*, *śatāvari*, three myrobalans, *girikarṇi*, *haṃsapadī*, *citraka*	—	Earthen vessel	*Śār. Sam. Madhya khaṇḍa* XI. 13. *Caraka* Cikitsā V.77. *Rasaratnākara of Nityanātha*, quoted in *Rasaratnasamuccayaṭīkā*. 115p.
Sauvīraka	Barley (coarsely powdered and then fried)	Medium-cold decoction of roots of prescribed plants.	—	Earthen vessel	*Suśruta Sū.* XLIV. 208-209
Śukta	Mixed substance consisting of treacle, honey, fermented rice water, whey and the like.	—	Deposition in heaps of paddy. Duration - three nights (in summer)	Earthen vessel	*Caraka, cikitsā, XIX.9. 212 Cakra-saṃgraha Grahaṇī-cikitsā* SL.31-32; *Vātavyādhi SL. 100. Śār. Sam. Madhyakhaṇḍa* XI.10
a)*Guḍa-śukta*	Molasses-water (associated material - oil and plant products).	Molasses water	—	—	*Śār, Sam, Madhyakhaṇḍa* XI.10.
b)*Ikṣu-śukt* & *Mṛdvika-śukta*	Sugarcane juice Grape(not fully matured)	—	—	—	*Śār, Sam, Madhyakhaṇḍa* *–do–*
Tusāmbu or *Yavāmbu*	Ground barley	Medium Water	—	—	*Ibid.* 12.

I. Distinguishing traits not common in world context.

(i) Fermentation concerned mainly or preparation of intoxicating drinks and acetic acids than several food articles involving fermentation, prevailed in Egypt and Mesopotamia.

(ii) Fire-heat rarely employed for fermentation.

II. Identical marks

(i) Fermentation with the aid of cereal grains.

(ii) Use of oleaginous substances or milk products in fermentation.

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Technology of Food

K. T. ACHAYA

Introduction

The processing or technology of food in by-gone India can conveniently be considered under three broad heads. The first, post-harvest operations on agricultural crops, would include grinding, pounding and winnowing. The second, domestic operations and appliances, would embrace those of both kitchen and table. The third category would be large-scale processing carried out essentially outside the home by professionals, such as warehouse storage, professional cooking, sugarcane and oilseed processing, and salt or alcohol production,employing appropriate technologies for each purpose.

Post-Harvest Operations

Grinding and pounding

Saddle querns for grinding grain or spices go back, all over the country,to neolithic and even mesolithic times,growing larger and more sophisticated with time (Sankalia 1977a,p.254).The upper stone, from being just a simple flat or round pebble, was dressed to become a muller, which could be plano-convex or biconvex for use with a flat stones, or biconcave when paired with querns curving inwards or outwards (Sankalia,1964). The Indus Valley settlements revealed two types of querns. One was more or less flat, with a cylindrical muller that could be rolled over it with both hands, as is done today for grinding chutnies. The other had a small depression, a round grinder, and a mainly crushing action, so that grains had probably to be soaked overnight before they could be ground in these querns (Sankalia 1977a, p.254). The action is shown in the well-known clay figure from Harappa, and much later is depicted in sculpture on an eastern gateway panel in Sanchi. The latter is a 4-legged flat quern, which was first found at Harappa, but

occurs more commonly in early historical and subsequent periods,like the Maurya-Gupta, all over north India and the Western Deccan (Ray, 1986, p.137).

In these sites also occurred a heavy rotary quern in two parts, the upper portion of which had two circular holes opposite each other through which a wooden pole could be introduced; two persons sitting opposite each other could then work this portion against the flat lower cylindrical base stone. Later, on the rim of the upper stone was provided a single socket in which a stout upright wooden peg could be affixed for circular movement by a single person. It has been argued that the earlier type is indigenous (Sankalia, 1987, pp.39-54) while the latter with a single peg was introduced during Roman contacts in the early Christian era (Dikśhit, 1939). A very large heavy circular stone with a central hole has been found at Lothal (Dikshit, 1939) and Mohenjodaro (Mackay, 1938, Pl. 54, Item 20). One view is that this object represents a stratigraphical displacement (Dikshit, 1939); another is that the stone could be a large pulley for drawing water from wells (Bag, 1985, p.43) and not the upper half of a *cākki.*

For dehusking grain a pounding and shearing action is needed. A mortar firmly fixed in a large hole built into the brick floor was unearthed at Harappa (Sankalia, 1977, p. 254), and a row of brick-lined pounding platforms with a central hole at Mohenjodaro (Sankalia, 1987, pp. 39-54). Stone mortars have been found at chalcolithic sites and at Mohenjodaro (Sankalia, 1977, p.254). A panel at Sanchi showing village activity depicts a woman, using a long (probably wooden) pole, pounding something in an hourglass- shaped mortar almost certainly made of stone (Dhavalikar, 1965). The Lakṣmaṇa temple at Khajuraho, of the 10th century A.D. shows what appears to be a wooden mortar and pestle (Prakash, Vidya, 1967, p.127). In the *Daśakumāracarita* of the 6th or 7th century A.D, a detailed description occurs of a cooking episode (Kale,1925, pp.111-115),in which a girl polishes dehusked rice by gentle pounding in "a mortar of *arjuna* wood having an upright pole, not very deep or spacious, stirring it up again and again with her fingers, and striking it with the heavy pestle of khadira, with its end covered with iron plate and even-shaped,and with the slenderness of its middle part noticeable, her arms fatigued with the up and down motions". The southern origin of the author Bāṇa is inferred from the characteristic iron-covered tip of the pestle; this also finds mention (*Rasanayagam*, 1926, pp.130-160) in one of the songs of the Tamil anthology, *Paṭṭupāṭṭu*, placed about the 3rd century A.D, which describes "white rice well cleaned in pounders set in iron rings"

Vedic Sanskrit has the word *dṛṣad* for a grinding quern probably of the flat stone type.The words for a mortar and pestle *ulūkhala* and *musala*, are believed to have been borrowed from even older usage (Shendge, 1977, p.241).

In south India, grain crushers, mealing stones, and mortars and pestles have all been found in neolithic sites (2nd millenium B.C.) like Brahmagiri, Tekkalakotta and Jorwe (Dhavalikar, 1970, p. 32).

The *dhenki* or foot-pounder is popular for dehusking paddy to yield brown rice, especially in eastern India and along the Indo- Gangetic plain. Being made of wood, old specimens cannot be expected to survive, but surprisingly it does not appear to be depicted even in sculpture anywhere. The device must be of atleast some antiquity, since it is the vehicle of Nārada (Wilkins, 1890, p. 479), who is himself

one of seven great *ṛsis* of the *Ṛgveda* (Dowson,1928, p.218), and is worshipped at domestic ceremonies like marriage, *upanayanam* and *annaprasanam* (Wilkins, 1890, p. 478).

Winnowing

The Sanskrit *surpa* or winnowing tray to remove chaff, for example after rice pounding, is also believed to be a borrowed wood (Shendge, 1977, p, 241), indicating even prior usage of this device. For winnowing large amounts, pouring the material from a height in the open in a natural mild breeze is commonly employed.

There is an interesting indoor variation in use to create a draft, whose antiquity is not known. This employs a large sheet of cloth, two adjacent corners of which are loosely pegged to the ground. The other end is flapped up and down by a standing woman, and seeds to be cleaned are slowly dropped, from above the pegged ends of the cloth, into the air currents so created.

Domestic Operations and Appliances

Devices and methods

Cūlās : Several houses in the Indus Valley settlement of Kalibangan had both underground and above-ground mud hearths, the latter with a comfortable bridged side-opening for feeding fuel (Ghurye, 1979, pp. 372-380). *Cūlās* with knobs, both of round and square shapes, and with one to three mouths, have been unearthed in sites at Ahar, Navdatoli and Jorwe dated 1500-1000 BC (Sankalia, 1977, pp. 100-124) and in Atranjikhera dated 600 BC (Ghurye, 1979, p.400). One of the Ajanta frescoes depicts a kitchen with knobbed *cūlās* (Yazdani 1952, pp, 58, 104), and they persist in India to this day.

Ovens : Baking ovens of various sizes have been excavated in Mohenjodaro, but some at least are really very large kilns for firing pottery objects of large size (Sankalia, 1970, p.13). Baking (*puṭapāka*), though known, is not a common style of Indian cooking.

Spits : The Vedic sacrifices (as we shall see) involve roasting a whole animal, or pieces of meat, on skewers or spits. In cooking language, *tanduram* means grilling and *bharjanam* dry roasting (Krishnamurthy, 1984, p. 227). At a picnic described in the *Mahābhārata* (Sengupta, P. 1950, p. 547), "cleanly cooks under the supervision of diligent stewards, served large pieces of meat roasted on spits...... young buffalo calves (were) roasted (whole?) on spits with ghee dropping on them". A *Paṭṭupāṭṭu* poet (*Rasanayagam*, 1926, pp. 130-160) of the third Tamil Sangam period (about the 3rd century AD) describes "fine large pieces of fat meat roasted on iron spikes" and elsewhere roasted pork is noted with relish (Nilakantha Sastri 1958, p.130). The modern *kābāb* has an old history.

Grilling : Though a *tāvā* for grilling does not seem to have been specifically identified in the Indus Valley, a typical dough-kneading plate with sides sloping outwards was recovered at Mohenjodaro (Mackay, 1938, Pl. 64, Item 13). The *Sūtra* literature rocords the baking of flat cakes on a broken earthen jar (*kapāla*), and a

grilling vessel (*vapāsrapaṇi*) (Prakash, Om, 1961, pp. 34-57). Among the items of the sacrificial *purodaśa* offering described in the Gṛhya sūtras is the *apupa*; this "implies a great advance in the art of baking," in that it is a cake baked on a flat vessel and a pan with a varying number of hollows resembling dishes, yielding a variety of shapes to the cake itself (Apte, 1939, pp.95-102). A stone with depressions is still in use in parts of south India to bake a type of rice *appam* called *kuzhi*. Several baking techniques recorded in the 17th century AD in Karnataka (*Sūpa Śāstra*, (a), p.268), but probably in traditional use much earlier, were: baking on a hot flat or concave griddle (*battala*) ; on a hot tile (*kencu*): between two plates with live coals placed both above and below; and directly on coals, after which the outer charred crust was discarded before consuming the cooked core.

Steaming : The Chinese pilgrim Xuan Zang in the 7th century AD stated that "India does not know the use of the steamer". While specific devices may not have been in widespread use, steaming as a way of cooking was known. The *Bṛhatsaṃhitā* of Varāhamihira, dated about 505 AD, describes a barley dish, *yavaka*, as *svinnabhaksya* or a steamed food (Shastri,1969, pp.209- 216). Among traditional cooking operations were *svedanam* or steaming, the others being *bharjanam* (dry roasting), *talanam* (drying), *apakva* (frying), *pacanam* (cooking in water), *kvatanam* (parboiling), *tanduram* (grilling), *puṭapāka* (baking), and *bhāvita* (seasoning). A Kannada work written in 920 AD mentions the idalige (idli) (*Sūpa Śāstra*, (b), p.255), and steaming was probably achieved, as it was slightly later, by the simple expedient of tying a cloth (on which the material was placed in lumps or small wicker baskets) over the wide mouth of a vessel in which water was boiled. A related product, the *kaḍubu*, was not through-steamed like the porous *idli*, but spread out on leaves or trays and surface-steamed to a denser product. In making the *puṭṭu* of Kerala, alternate layers of broken rice and coconut are introduced into a wide bamboo tube in which a pierced metal disc is placed on the lower node. A funnel is loosely inserted on top for steam to escape, and the tube is then tightly fixed on the spout of a vessel in which water is boiled to effect steaming. The antiquity of this simple domestic technology remains to be established. A vessel that occurs commonly even in many neolithic sites, and later in the Indus Valley, is a tall earthen cylinder with perforations all over it (Wheeler, 1959, p.103); one use suggested for this, among many others, is that it is a vessel for steam cooking (Ghurye, 1979, p. 383).

Cooking under pressure : The virtues of cooking over a slow fire is noted in the *Bhela Saṃhitā* (c. 150 AD) (Prakash Om, 1961, pp.87-101) and again a century later in the *Viṣṇudharmottara Purāṇa* (Prakash Om, 1961, pp.203-239). Now generally called *dumpukht* or simply dum cooking, this involves slow simmering of the materials in a vessel, on which a well-fitting lid is sealed all round using a thick dough of wheat. The practice is called *kaṇikā* in Kannada, and is mentioned in a work of 1606 AD (*Supa Śāstra*, (b), p. 255), but is probably older. It is in common use even today for making pullao all over the country, live coals being placed both below the vessel and on the lid for slow, gentle baking with aroma retention.

Founding and cleaning rice : Rice pounders have already been described under post-harvest operations, and domestic devices were no different. In the charming cooking vignette which occurs in the *Daśakumāracarita* (6th-7th century AD (Kale, 1925, pp.111- 115),the maiden, after pounding the grain, dries the mass briefly in the sun, turns it over and over, and then separates the chaff without breaking the grains by striking them gently with the edge of a stalk. Use of the *surpa* or winnowing tray for removing extraneous matter like sticks and stones from grain at any stage must go back at least to its first mention in Vedic times. The *Amarakośa* (c.450 AD) lists two names for sieves, *cālāni* and *titau* (Deshmukh, 1981, pp.99-110).

Churning butter: The Indus Valley seals depict bulls, among them those of the Kankrej breed (Randhawa, 1980, p.184, Fig.96), pointing to the distinct likelihood of dairy operations which could well have included the churning of soured milk into butter. The *Ṛgveda* has several references to the churning of curds with a corrugated stick, the mixture after the operation being termed *prasadiya* (Prakash, Om, 1961, pp. 34-57). Freshly-prepared butter later acquired the name *navanitha*, while butter prepared from fresh milk was variously termed *phanta* (Pāṇini),*kṣirotanavanitha* (Suśruta) and *payasarpis* (Varāhamihira) (Shastri, 1969, pp. 209- 216). The Lakṣmaṇa Temple (c. 925 AD) at Khajuraho shows in *Kṛṣṇa-Līlā* scenes a stick, standing in an earthen pot, which was churned with the help of a rope (Prakash Vidya, 1982, p, 127) exactly as is done at present. Another charming butter-making device of unknown antiquity common in parts of south India is a convex piece of coconut shell with three pierced holes, fixed on a long bamboo stem; this is worked up and down in a tall cylindrical bamboo or tinned copper vessel to achieve concussion and release of butter in the diluted curd that is being churned. A beautiful Tamil poem, *Perumpanūrrupadai* in the *Paṭṭupāṭṭu* anthology of about the 4th century AD (*Rasanayagam*, 1926, pp. 130-160; Srinivasa Iyengar, 1930, pp. 57-70) describes how the cowherdess sells buttermilk that has been made by "pulling the strings of the *mattu* (churning rod) which creates a sound resembling the growl of a tiger". The curds themselves are noted as having earlier been seeded using a pat of the previous day's curd which looked like a "white mushroom".

She then sets off on her selling errand "placing the pot, with its speckled mouth, on her head supported by a circlet of flowers". The Sangam literature of the period is replete with references to cream (*eḍu* or *perugu*), curds, buttermilk, butter and ghee (Srinivasa Iyengar, 1930, pp. 57-70). The finding of vast mounds of ash burnt from cattle dung, dated around 2200 BC, in many sites along the valley of the River Krishna in south India (Allchin, 1963) would argue for the existence of cattle keeping and dairy products from times long before the Aryan advent.

Kitchen and table utensils

Indus Valley : Among drawings of the metal objects found at Mohenjodaro (Mackay,1938 b) are to be seen the following: a *thāli*–like pan (Mackay, 1938 b,

Pl 68, Item 20); a flat deep dish with sides sloping outwards resembling a modern dough-kneading pan (Mackay, 1938 b, Pl. 64, Item 13); a round, concave *tāvā*-like plate (Mackay, 1938 b, Pl. 82, Item 3); and a copper frying pan with the edges turned inwards to create a comfortable handle, either long or short (Mackay, 1938 b, Pl. 71, Item 42, Pl. 82, Item 11). The *thāli* (there are actually two of them of slightly different sizes) is again seen in a photograph of a hoard of copper and bronze objects, all corroded together (Mackay, 1976, Pl. 19), found beneath the floor of a small house; this also shows a largish tray with a wide, flat rim. Another heavy copper pot of exquisite design with a square open top was found at Mohenjodaro (Dikshit, 1939), and resembles the *kumbha* of current times used for fetching water from well or river.

Numerous copper and bronze objects were found at Chanhudaro, which was apparently a great centre of metal working; one was a lota-shaped vessel with a long spout pointing up from near the base (Allchin, 1963). Kitchen knives made of ribbon flakes of chert were plentiful, and even the cores from which they had been struck were found in abundance (Allchin, 1963).

Nearly a thousand copper objects that preceded the Harappan civilisation were found at Ganeswar; it appeared to be a manufacturing centre that employed copper ore from Khetri, and perhaps supplied the needs of nearby towns like Kalibangan, Mohenjodaro and Harappa (Agrawala, R.C.,1984, p. 157). Copper ore from the Aravalli range was certainly the source of the metal over a good part of the area (Agrawal amd Ghosh, 1973 (a), p.401). Scarcity of tin, which forms 10-20 percent of bronze, accounts for paucity of objects made of the latter, even though they are harder, keener and more cutting than those of pure copper (Agrawal and Ghosh, 1973,(a), p. 401). Iron is first noticed about 800 BC in a few megalithic sites; the Vedic word *ayas* is now believed to have first meant copper, which was later termed red *ayas*, after the use of iron, called either. white *ayas* or *loha*, became common (Chaudhuri,1988, p. 321). Initial use of iron was for weapons or agricultural implements like ploughshares. Its real impact occurred after about 200 BC, when its carburation to steel incorporating about one percent of carbon was discovered (Agrawal and Ghosh, 1973,(b), p. 391) and the use of the bellows enabled greater heat intensity. Both bellows and iron ploughshares are frequently referred to by Pāṇini (Thakur, 1932, pp. 111-112).

Vedic Period : Even the *Ṛgveda* mentions a large number of utensils (Prakash, Om, 1961, pp. 34-57, Iyengar, 1932, pp. 28, 47 ff.). Special *soma* storage vessels were the *amatra, ahara, kośa, dru, kalasa, camu* and *droṇa*, and for other liquids there were vessels like the *kumbha, acecana*, a gold *kalasam*, a bag for milk (*dṛti*), a water bucket (*udañcana*) and nested vessels (*dhiṣana*). *Patra, camasa* and *graha* were drinking cups, while *ukha, garma* and *pacana* were cooking pots, and *caru* a covered cauldron. Spoons and ladles included the *juhu, upasecani, śruk, śruva, darvi* and *neksanam*, while *pavitra* and *karotara* were strainers, and *suna* and *svādhiti* were knives. *Grāvan* and *adri* were grinding stones for soma, *ulukhala* and *vanaspati* (later called musala) were a mortar and pestle, and *dṛsad* a flat grinding stone. *Śūla* was a roasting spit, *dhamatr* a blower or bellows, *titau* was a sieve, and *surpa* a winnowing

basket of wicker. A general term for a leather cask used to store water, liquor and curds was *dhrti*, and for a leather bag *kṛvi*. A minority opinion was that the *ulukhala* was a shallow, wide-mouthed mortar for grinding, while the *musala* was the long heavy, waisted pounder (Sircar, 1967, p. 194).

Table 1 — Utensils of The Vedic Sacrifice

Containers		
pātra	:	sacrificial wooden vessels, placed in pairs on the sacrifical grass, and of five kinds (*upaṃsu-*, *urdhva-*, *ṛtu-*, *śukra-* and *manthi-*) for different uses
sambharani	:	wooden vessel in which is placed the wet, pounded soma stalks
droṇakalāsa	:	bucket-type vessel covered with a filter to receive strained soma juice
pūtabhṛt	:	clay trough to hold prepared soma juice
camasa	:	oblong tub with handle, of ten types, for use by different priests for various purposes, such as: holding soma, drinking soma (by the priest); holding sacred water; and holding food in the vow rite
agrāyanasthāli	:	vessel to receive strained soma juice in the agricultural rite when new fruits are eaten
śarāva	:	earthen dish holding water with which a new mother is sprinkled
pinvana	:	two milk vessels
sarpirdhāna	:	bowl for butter
idapātra	:	deep oblong container with a flat rim to hold ghee
pranitapranāyana	:	-do-
nināhya	:	earthen waterpot buried in the ground to keep its contents cool
Large earthen cooking pots		
ukha	:	square pot used to boil flesh
mahāvirā	:	wide-mouthed pot in which milk and ghee are heated
gharma	:	large earthen pot in which milk is boiled
kumbha	:	cooking vessel in which rice is boiled
śrāpana	:	cooking vessel
Ovens, Baking, Roasting		
culli	:	clay oven
kuplu	:	-do-

contd.

(Contd. Table 1)

bhrāstra	:	-do-
śūla	:	skewer of wood on which certain animal organs were roasted
gārhyapatya	:	potsherd for taking purodasa
kapālas	:	-do-
Fire Utensils		
araṇi	:	a spindle (worked with a length of string) and a wooden board with a friction hole
sata	:	two large vessels for carrying embers
pariśāsa	:	tongs to lift the gharma from the fire
upavesana	:	wooden poker for stirring the fire, and for removing embers
dhṛṣti	:	a pair of pokers used to stir the fire and to remove embers
Strainers		
pāvitra	:	strainer made of sheep's wool for filtering soma juice
karotara	:	a strainer
Ladles, Spoons		
śruk	:	collective term for large wooden ladles used for libations, with a yoni-shaped bowl ending in a lip
juhu	:	a sruk
dhruva	:	-do-
upabhṛt	:	-do-
pracarani	:	-do-
darvi	:	a small ladle with a long, slim handle and a tiny, lipless bowl for sprinkling libations
śruvi or *śruva*	:	-do-
tragbila	:	-do-
vitasti	:	-do-
pariplava	:	spoon without a handle for drawing out soma
havani	:	spoon, used e.g. by the agnihotṛ
grahani	:	spoon, used e.g. to hold the prasadaiya of butter and buttermilk
pariplupātra	:	a ladle
antardhāna	:	-do-
prasaka	:	a decanting vessel with a long handle and a large, cup-like bowl
Offering Vessels		
vāyavya	:	waisted, spouted cylinder used to make offerings to twelve deities

contd.

(Contd. Table 1)

urdhvapātra	:	waisted, spouted cyinder
anvaharyasthāli	:	-do-
agrayanasthāli	:	-do-
akaraphalika	:	snake-shaped board, one-arm long, on which sesame seeds are offered in the sacrifice
Stirrers, Scrapers		
parsva	:	stirrer-spoon for the *vasa* (marrow)
makṣana	:	wooden scraper with a square, flat head for stirring flour and boiling water in preparing purodasa; it is discarded after use
Cutters		
svadhiti	:	knife to dissect sacrificed animal
sāsa	:	kitchen knife
sphya	:	wide, dagger-shapped wooden implement used for several purposes in the sacrifice
Pounders, Grinders		
ulūkhala	:	wooden mortar
musāla	:	wooden pestle for the ulukhala
dṛśad	:	lower, flat grinding stone
dṛśadputra	:	upper milling stone
upala	:	-do-
pesani	:	the two milling stones taken together
Baskets		
palva	:	winnowing basket holding sacrificial grain
śūrpa	:	winnowing tray of bamboo or reed
Leaf Utensils		
pātravali	:	plate or cup made of leaves stapled together with splinters
pārṇapuṭa	:	a funnel of folded palāśa leaf, in which a lump of boiled rice is hung on a tree.

The Gṛhya and Śautra vedic sacrifices enshrined in the *Sūtras* employed an enormous number of utensils of rigidly specified design and structure. These are shown in Table 1 (Vesci, 1985; Sen, 1978). The soma rites were performed three times a day, and employed twelve main vessels for various types of cooking, like *sthālipāka*, cooking in a pot, and *śutagrāva*, roasting on a spit. The *pravargya* rite, which is part of the soma sacrifice, required the making each time of a special, round, fired clay vessel with a wide mouth called a *mahāvīra*, which is heated intensely in the course of the rite (Vesci, 1985, p. 215). For the *ajamedha*, or goat sacrifice, a special clay cauldron called the *gharma* had to be made for cooking the

meat (Vesci, 1985, p. 69). The *aśvamedha* or horse sacrifice also called for a huge square clay cauldron termed the *ukha* for cooking the flesh, and hollow metal skewers for roasting certain organs after their dissection (Vesci, 1985, p. 32). In contrast to the potter's wheel that was in use much earlier to turn clay in the Indus Valley, these large clay vessels had all to be kneaded by hand to exacting schedules using certain special clays (e.g. from an ant-hill, or from a place snouted open by pigs). Similarly the *aṣṭaka* cake had to be made with exactly four full *śaravas* of rice. The sacrificial *puroḍāśa* cake of rice or barley flour had to be baked in a flat clay vessel with a specific number of hollows of various shapes for different purposes (Apte, 1939, pp. 95-102).

Not surprisingly, some of these vessels, like the *drona*, *kumbha*, *kalasa*, *ghaṭa*, *śārava* and *sthāli* later became volume measures (Srinivasan, 1979, pp. 71-79).

Many objects from these Vedic times are instantly recognisable as being in use even today. The *culli* is the *cūlā* of the present, the spit is in use by Rajputs for roasting a whole pig to give a dish called *śūlā*; the scraping utensil *dhṛṣti* is now the *kunti*, the flat grinding stone *dṛṣad* with its cylindrical roller is found in every Indian kitchen, and a deep form of the stone mortar with its stout upright grinding stone is an essential item in a south Indian home. *Kalāśas*, *kumbhas* and *pātras* are all with us, often in metallic form, as are the *bharjanapātra* as *kaḍāhi* (from *kaṭāha*, a word of Prakrit origin (Sagar, 1933, p. 184) that occurs in the *Rāmāyaṇa*, *Suśruta Saṃhitā* and *Sūryasiddānta* (Monier Williams, 1851, p.549), the *ajyasthāli* as *tāvā*, and the small waisted cylindrical kitchen mortars for pounding spices. Leaf plates and cups, then *pātrāvali*, now *patroli* or *paṭṭal*, are still in use. Some old utensils have altered. The small soma pounder is now a tall cylindrical vessel to be worked by a person while standing, and the sthāli has changed its name to *thāli*, and its function from a cooking to an eating utensil.

Utensils of later times : Panels dated 50-20 BC in the great stupa at Sanci depict a ladle for ceremonial libations, a small goblet with crossed straps, and a beautiful spouted ewer with a fitted lid and a curved handle on top like a modern kettle (Dhavalikar, 1965).

A Buddhist monk was permitted to carry eight items : *bhṛṅgāra*, water jar; *saraka*, drinking cup; *thavika*, water bag; *piṭaka*, basket; *kumbhi*, cooking pot; *tattaka*, plate; *pariyoga*, dish; and *kadapiyan*, pan (Prakash, Om, 1961, pp.58-86). Utensils mentioned by Patañjali (mid-2nd century BC) include a tiny water-jug, *kuṇḍikā*, for the use of students, and a cauldron, *ūkha* (Puri, 1957, pp. 89-115). The *Rāmāyaṇa* mentions three drinking goblets, *śārāva*, *karaka* and *golvarka* (Sharma, 1971, pp. 232-242), an iron pan *lauhi*, a deep frying pan *kaṭāha* (modern *kaḍahi*) and a boiler *pithara* (Prakash, Om. 1961, pp. 102-131). The *Amarakośa* (5th century AD) includes the deep frying pan *kaṇḍu*, the roasting plate *bhrasta* (*tāvā?*), ladles *kambhi*, *kajaka* and *tardu* (with a wooden handle), strainers *karkari* and *galantika*, a goblet *kausa*, a pot *pithara* and leather bottles *kutuh* and *kuṭup* for storing oil (Deshmukh, 1981, pp. 99-110). The portable *śigrī* of today was called *cūlli*, *aṅgāradhanika* or *hasauṭi*. Kālidāsa has *kumbha* for a big pitcher, and *ghaṭa* for a small one (Upadhyaya, 1947, p, 216). At three places in the *Harṣacarita* occur various utensils, though mentioned in rather a tangle (Cowell and Thomas, 1961). These have been sorted out (Agrawala, 1940) as various very large water pots

alinjara, *mahakumbha*, *gola* and *kantakita* (also called *panasa*, since it has the shape of a jackfruit), small pots *kusumbha*, *karkari* and *votakuta*, jars *kalasa* and *kumbha*, a cup *kosa*, and an earthen vessel for molasses (*phanita-sthāli*). Frying pans (*kaṭāha*) are here again, besides baking trays *talaka* and *sakatika*, simmering pans *tapika* (Hindi *tai*), the saucepan as *caru*, the *tāvā* as *tapaka*, spits as *hastaka* and *śūla*, and baskets as *pitaha*.

The Ajanta paintings of about the 8th century AD show kitchens with a *cula*, and globular cooking pots, placed one over the other, slung from the roof (Yazdani, 1952, pp. 58, 104; Schlingloff, 1987, p. 104).

Utensils in south India : Some of these have already been described in the preceding section under the subhead 'Devices and Methods'. The literary record may now be considered.

The oldest Tamil writings of the Sangam period (Srinivasa Iyengar,1930, pp.57-70 and 1932, pp. 253-300; Sreedhara Menon,1979, pp.121-126); date from about 100 BC to the 6th century AD, when kingdoms and trade were flourishing and kitchen technology must have already come a long way. The *ural* and *ullūkal* (words that obviously resemble the Sanskrit *ulūkhala*) were mortars made of both wood and stone used to pound paddy and rice. Grinding stones frequently took animal shapes, such as that of a tortoise; they were called *ammi*, *tiruvai*, *āttukal and kulavi*, while the stone mullers that paired with them were termed *puttil* and *vatigai*. Pots were fashioned out of either clay or stone, and had many names; *pānai*, *śatti*, *śal*, *talam*, *midā*, *pāñā*, *mittava*, and *mallāy*, with its lid *madukku*. Liquor was served in a bowl called *mandai* (Subrahmaniam, 1966, pp. 306-309). The *kundam* was a versatile container, used for example to hold toddy (*kallu kuṇḍam*), and so was the *kalam*. Pots could be suspended from the roof in a rope sling (*simili*), or kept in stands called *paṭṭādai*, *śumudu* or *śummadu*. There were many spoons: the *agappai* was itself of three kinds (*tatta-*, *sanda-* and *sirra-*), and there were others called *sattuvam*, *karaṇḍi*, *muttai*, *taduppu*, *maravai*, *ṭoṭṭi*, *kinnam*, *marakkal* (or *abanam*) and *vaṭṭi*. The *vattil* was a flat spoon of stone, wood or metal. There were wood friction devices to raise fire, censers to hold embers (*tadavu*, *indalam*) and pokers (*nelikol*) for raking the fire. The winnowing pan (*śurpa* in Sanskrit) was *murram*, the sieve was *salladai*, and there were plates called *sinnam*, *sulagu*, *tattu* and *mirrul* for various purposes. The bamboo coop for protecting food from flies was called *kudu*. Kitchens had mats (*pāy*) to sit on, and lofts for storage (*paran*, *idanam*, *kaludu*, *padagam* and *panavai*). Leaf plates fashioned out of the *ambal* (lotus), banyan and teak are mentioned in the earlier literature; by the 8th century AD, use of banana leaves had become common (Pillay, 1975, p. 284). Practically all these utensils and words persist to this day. As in the north, some vessels later evolved into measures of volume, like the *kalam*, *padi*, *nāli* and *ūri* (Srinivasan, 1979, pp. 71-79). Fire was raised by friction between pieces of wood, and a perpetual fire was kept going in pots called *kumpatti*. Into this was poked a stick called *sulundu*, sometimes tipped with sulphur (Srimvasa Iyengar, 1930, pp. 57-70).

A vessel that today is considered distinctively south Indian is the *kūja*, a clay drinking water-storage vessel with a globular base and a stout neck, of about the same height as the base, flaring slightly outwards. It has first been noted in

Cemetery H of Harappa, which is a repository of utensils of unknown origin that differ from those in the main settlement (Sankalia, 1971, p. 259), and later in Jorwe about 1600 BC (Dhavalikar, 1985, p. 3). Thereafter the utensil disappears, to reappear about 1300 AD after the Muslim advent. Its antiquity in south India is not known.

Lacking copper ore, south India largely skipped the chalcolithic stage, and copper utensils have been found only in a few sites like Hallur, Tekkalatotta, Utnur and Payampalli between 2500 and 900 BC (Sankalia, 1970, p. 45). Iron came into use even by 1000 BC to make hunting weapons and agricultural tools. Later came domestic utensils, but those made of stone and earthenware are preferred for cooking even to this day.

Except for some items of specific regional utilty, it is clear that all over India domestic utensils are very much the same. Writing in the early 18th century AD in Sanskrit, King Basavarāja of Keladi (Krishnamurthy, 1984, p. 227) in present-day Karnataka uses Sanskrit terms without awkwardness to denote many utensils then in use in a southern kitchen, like *gharatta* for grinding stone, *pravani* for frying pan and *kharpava* for *tāvā*. Regionally, Punjab has the distinctive *tandoori* baking oven. Kashmir has items with a Central Asian association like the *traemsarposh* used to serve Wazwan food, the *khanḍakari* or *samovar* used in brewing the aromatic kahwah tea, and certain distinctive ladles used in cooking and serving.

Large-scale Operations

Food storage

Granaries for grain storage of surprising sophistication and size have been found at Mohenjodaro, Harappa and Lothal. On a high brick-built base at Mohenjodaro were set some 27 storage blocks of wood arranged crosswise, with vents on the sides to ensure air circulation by convection (Wheeler, 1976, p. 86).

Half-way up the structure was an unloading platfrom; this could be approached by carts carrying grain, which probably arrived along the river. Adjoining the granary were a row of brick-lined pounding platforms with a central hole, still carrying fragments of burnt wheat and husked barley. At Harappa, the mud platform, situated again by the river, was 52 by 42 metres, and 1. 2 metres high, and on it stood two identical granary blocks about 7 metres apart (Vats, 1940, I, p. 15 &II, Pl.6). Each block had six chambers, with corridors between them opening outside and approached by a short flight of steps. The floor was raised off the ground to permit air to circulate, and small triangular vents sucked in this air to pass through the chambers. Some form of state authority was clearly involved in the procurement and distribution of grain on a large scale. At Lothal, the granary, or perhaps warehouse, overlooked the dock (Rao, 1962, pp. 14-30). It was 51 by 45 metres and stood on a platform 3.5 metres high. The vanished wooden granary, probably destroyed by fire, appears to have rested on palettes or blocks 3.7 metres square and a little over a metre high. Never in Indian history till recent times was grain to be stored on this scale.

Professional cooking and dining

Royal cooking : The royal kitchen was called *rasavati* or *mahānasa* (Auboyer,1965, p.265).That of king Sandāsa is depicted as merely an open thatched hut in Cave 17 at Ajanta(Schlingloff 1987,p.109). The cook is seated on the floor, pointing to a cooking pot with one hand, while looking at the back of the hut, where a dog is seen that has made off with the meat destined for the royal table. Among a king's morning tasks was a consultation with the cook. The cook's duties were not only to keep away marauding crows and dogs, but to ensure food variety and freedom from poison for which an official food-taster was always around (Auboyer,1965, p.259). The cook was called the *ālārika* or *sūpakāra* (Law, 1934, p. 68), and there were specialists like the *avalika* (for use of condiments and spices), *apupika* (for baking) and *kandavika* (for frying) (Deshmukh, 1981, pp.99-110). Buddhist literature has *odanika* for a cook, the *Arthaśāstra bhojanadātṛ*, and the *Viṣṇu Purāṇa sudas* for a king's cook (Dayal, 1983, p. 157). In pre- Aryan south India, lavish hospitality was expected of royalty; one poet was fed with the "soft boiled legs of sheep fed on sweet grass, and large chops of hot meat roasted on the points of spits... (besides) sweets of excellent taste in varied shapes", and of course strong liquor, sometimes scented and flavoured.

Public dining : The austere Vedic and Brahmin injunctions on food purity and ritual precluded their eating in public, but the rest of the population had no such inhibitions. In the commercial districts of the city were shops (Auboyer,1965, p.121) piled with "cooked rice and prepared food ready for eating, whose pungent odours assailed the nostrils". Early European visitors to north India describe Lahore's "brilliantly lighted bazaars which had a great number of occupied tents or cookshops exhaling the aroma of spicy dishes" and displaying "large spits bearing the flesh of winged creatures... nor did these bazaars lack the simple foods of the native, (to meet whose taste) many tents hold different dishes made of rice, herbs and vegetables (besides) the ubiquitous flat bread".

In Agra (Sebastian, 1982, p. 263) "entire streets are wholly occupied by skilled sweetmeat makers (with) dainties of all sorts in the innumerable bazaars".

Early south India had few dining taboos, and eating in hotels must have been a common practice. One work of about the 3rd century AD, *Mathuraikkañcī*, describes (*Kanakasabhai*, 1904, pp. 125-135) thus the market place of Madurai; "the hotels and restaurants are now, in the cool of the evening, crowded with visitors who feast upon luscious fruits such as the jackfruit, mango and plantain, and on sugar candies, tender greens, edible yams, sweetened rice and savoury preparations of meat". In the heyday of Vijayanagar in the 16th century AD, visitors like Varthema, Barbosa and Paes describe the markets overflowing with meat and vegetables (Randhawa, 1982, II, pp. 113-114).

These large establishments catering to cooking and feeding large numbers would not have required special preparation technologies, as at present, domestic practices on a larger or more intensive scale would have sufficed.

Alcoholic Drinks

Usage of liquor : This may be reviewed as a preamble to reviewing the technology of production. The Harappans may even have drunk distilled liquor (as shown below). The *Ṛgveda*, while exalting *soma*, condemns the use of *surā*, a distilled liquor. In subsequent Vedic literature, Brahmins (and students in particular) are always rigorously prohibited from using liquor, while Kṣatriyas and Vaiśyas are permitted liquor made from honey, *mahuā* flowers and jaggery, but not spirits distilled from fermented flour (Prakash, Om, 1961, pp. 34-57). The Jataka tales suggest that drinking at feasts with friends was by no means uncommon, and that women and even hermits imbibed. Buddhist monks were not permitted wine except when ill. For Jain monks, the prohibition was strict; they could not even stay in a place were jars of wine were stored.

Drinking was common among Kṣatriyas. Sītā promises the Ganga a thousand jars of wine if members of the party return safe from exile (Sharma, 1971, pp. 232-242). After they do so, Rāma feeds her with his own hands with *maireya*, a spiced wine. Outside the public indulge in a drunken orgy, and even the atmosphere of Ayodhya was said to reek of wine (Sharma, 1971, pp 232-242). In the *Mahābhārata*, Kṛṣṇa enjoys drinking freely with Arjuna, and the Yadavas are killed in a drinking brawl. Even a virtuous lady, Sudeṣṇā, is shown as drunk on wine. Drinking scenes are depicted in sculpture in the Sanchi stupa (Sharma, 1971, pp. 232-242), in Kuṣāṇa temples at Mathura (Dayal, 1983, pp. 96-104) and in Calukyan temples at Pattadakal (Kamat, 1978, p. 170). The *nagaraka* (man of town) of the *Kāmasūtra* sips drinks from a *casaka* while nibbling at sweet bitter and acidic snacks (chalakdar, 1976, p.17). In Kālidasa's plays (Pathak, 1978, p. 58) citizen and constable both indulge in drinks (*Śakuntalā*), and in *Raghuvaṃśa*, the whole of Raghu's army drinks coconut wine, and an intoxicated *Irāvathī* is not able to move about properly.

Public taverns or drinking areas are frequently depicted, and are called *saundikas* and *panabhūmis*. In Mauryan times (Auboyer, 1965, p, 259) "every village had at least one tavern, identifiable by the flag that it flew. The towns contained many taverns, grouped in the same district but sufficiently spaced out to prevent their being side by side. They were often decorated and furnished in style, and contained several courtyards, rooms filled with seats and couches, and also counters where perfumes, flowers and garlands could be brought. It was a lucrative business, for the sale of fermented and alcoholic drinks continued throughout the day and well into the night. The customers ate salt with their drinks to encourage their thirst". Moderation in use of liquor is urged, for example in the *Bṛhatsaṃhitā* (early 6th cent. AD) (Shastri, 1969, pp. 209- 216) and in the *Caraka Saṃhitā* (Chakraborty, 1923 p. 573), which opines: "A stimulant taken in proper dose increases the strength and weight of the body, but taken in excess it reduces the body weight". Elsewhere Caraka recommends a little wine only when the digestion is at its best, such as in winter and spring, and diluted wine in the rainy season and summer (Sengupta, 1919, p. 12).

Before the Aryan advent into south India, drinking was free of taint and indulged in at all levels. Even woman drank, especially in the company of their lovers. Toddy

was made by fermenting palmyra sap, and was drunk, as in *Manimekhalai* (6th cent. AD) by the poorer classes (*Kanakasabhai*, 1904, pp, 125-135). Poets wrote of sturdy sailors living a dangerous life, who were fond of strong liquor (Srinivasa Iyengar 1932, pp, 253- 300). Wine brewed from germinated grains in pots is mentioned more than once, and is drunk by soldiers, for example (*Rasanayagam*, 1926, pp, 130-160). Liquor shops in Madurai floated gay streamers (*Kanakasabhai*, 1904, pp. 125-135), and a piece of raw ginger chewed while drinking was recommended to the heavy imbiber as an antidote (Nilakantha Sastri, 1964, pp.77-80). Kings had access (*Rasanayagam*, 1926, pp. 130-180), at least during the 1st and 2nd centuries AD when trading with Rome was at its peak, to "cool and fragrant wine in golden cups, held by bright-bangled women". Even after the spread of the Aryans, Brahmins are sometimes shown as drinking toddy without reproach (Krishna Ayyar, 1966, p. 31). Kapilar, the famous Brahmin poet of the Sangam epoch, speaks with relish about both drink and meat (Pillay, 1975, pp. 224).

Production and types of liquor : Though it is made clear, by contrasting it with *sura*, that *soma*, was not an alcoholic liquor but an exhilarant (Prakash, Om, 1961, pp. 7-33, Sell, 1933, *Notes* pp. 152-170),its elaborately ritualistic production technology can conveniently be noted here (Vesci, 1985, pp.215, 69, 32, Sen, 1978, Three plates). The material, brought from a mountainous area, was first washed, and then either crushed between grinding stones (*grāvan*), or pounded in a mortar and pestle (*ulukhala* and *musala*) using both hands, while sprinkling water and sometimes squeezing the material to assist extraction. The *grāvan* stones were placed above four holes connected underground; the resounding echo of the grinding was poetically compared to the lowing of bulls. The liquid was filtered through a strainer of sheep's wool (*pavitra*) held above specified jars or wooden tubs. The amber, shining liquid was mixed with curds, ghee, milk, water, honey or grains before being drunk by the priests and the person making the sacrifice.

Was liquor made in the Indus valley? Perhaps not just brewed, but even distilled. Using clay objects found at all Harappan sites, a distillation unit has been assembled (Mahdi Hassan, 1979, p. 264). On the mouth of a water pot was placed a well-fitting circular basin with a wide circular hole at the bottom. In this was cradled a smaller basin with holes in its base. Alcohol boiled in the lower pot rose through the holes; was condensed on the underside of a handled receptacle holding cold water that was placed above the assembly, and then fell into the annular space of the fitted basin. The only special vessel required was the small perforated basin; this has repeatedly been found in excavations without a satisfactory use having been ascribed to it.

The *Ṛgveda* describes *surā* as an intoxicating liquor distilled after fermenting barley or wild paddy, and it may have had a connection with the hated asuras. Later Vedic literature (Prakash, Om, 1961, pp. 7-33) has *kilala* (a sweetened drink made from fermented cereals), *masana* (a filtered rice gruel liquor) and *pariśruta* (a product of fermentation of flowers and certain grasses). Subsequently numerous products find mention. The *Rāmāyaṇa* has four (Sharma, 1971, pp, 232-242), Kauṭilya names 12, and Caraka makes mention of no less than 84 kinds of alcoholic liquor. In Table 2, these alcoholic beverages are listed roughly in the order in which they are mentioned in Sanskrit literature.

Table 2 — Liquors Listed in Approximately Historical Order

Surā	The earliest-mentioned liquor made from barley or rice flour by fermentation, and perhapa used by the detested asuras. Later a generic word for a strong drink
Māsara	A fermented mixture of barley gruel, or rice gruel (*kanjika*), and spices, which was then filtered. Also perhaps Pre-Aryan
Pariśutra	Fermented flowers with added aromatic grasses
Kilala	Fermented, sweetened cereal-derived drink
Kalika	A kind of wine
Avadatika	A kind of wine, different from kalikā
Maireya	A liquor, probably distilled, flavoured with the tree bark of *mesasringi* (*Gymnema sylvestre*), with added guda (or sugar), pepper, triphala and spices
Kaśāya	A fermented extract of rice meal and flowers
Madya	A general term for a strong liquor
Vāruni	Distillate of fermented *mahuā* (*Madhuca indica*) flowers. Later also applied to the distilled ferment from dates and palm fruits, and perhaps for any strong drink
Madīra :	A general term for wine of high quality
Prasanna	Fermented rice flour, flavoured with spices, bark and. fruit, the name may be suggestive of the clarity of the drink
Śīdhu ;	Fermented and distilled sugarcane juice with dhātakī flowers (*Woodfordia fruticosa*). The red flowers contributed colour, astringent tannins and an alcoholic ferment. Amlasidhu may have had added amla fruit (*Embilca officianalis*)
Kādambari	A distilled liquor based on ripe kadamba fruit (*Anthocephalus cadamba*)
Tallaka	Wine from palm fruit juice
Jati	Wine flavoured with jasmine flowers
Khajurāsava	Wine from dates
Jambu-āsava	Wine from the jambu fruit (*Syzygium cumini*)
Medaka	Wine made from rice and spices. The name may suggest the fattening property of the drink.
Sahakarasurā	Wine brewed form mango juice
Mahāsurā	Mango juice wine with a high proportion of fruit extract
Rasottara	Wine from molasses
Kaula	Wine from ber fruit (*Zizyphus* species)
Śvetasura	A clear palm drink achieved by adding *Kataśarkara* and licorice decoction
Bijottara	Palm fruit liquor of some special kind

contd.

(Contd. Table 2)

Sambhariki	:	-do-
Divya	:	A liquor flavoured with kadamba tree bark
Āsava	:	A generic class of distilled liquors, named after the source; pushpa-, phala-, madhvika-, sarkara-, sura- and narikela-, perhaps later sweetened and flavoured
Ariṣṭa	:	Wines of medical connotation, as the name (meaning absence of injury) suggests
Kohala	:	Distilled liquor based on parched barley flour
Kaśya	:	A strong intoxicant

Apart from these, the nobility right from *Sūtra* times were able to import two wines which are repeatedly mentioned. One was *kapisayani* from *Kapisi* (now Kafiristan, north of Kabul), and the other was *harahuraka*, from a town *Harahura* in the Arghanbad valley. Both were famed for their wine, made from white grapes in the former city and black grapes in the latter (Goswami, 1979, p. 27). Excavations at Begram in the area have brought to light a complete and artistic distillation assembly in the shape of a jar from whose mouth emerged a pressing shaft topped by a conical filter (Goswami, 1979, p. 37).

The raw materials employed for brewing were quite varied. The *Rāmāyaṇa* mentions four *āsavas* derived from flowers, fruits, honey and sugarcane. *Caraka's* 84 varieties are derived from nine sources. Sugar-rich materials used for fermentation were sugarcane juice, guda, molasses, honey, coconut water, sweet palmyra sap and *mahuā* flowers, while fruits included the grape, mango, wood-apple (kapittha), date palm, ber, banana, apricot, jack-fruit, pomegranate, *kadamba, bilva, rajadana* (*chironji*) and *madanaphala* (*Mimusops elengi*). Flavouring materials included fragrant flowers like the *kadamba, paṭala, jati* and *dhātāki*, and spices such as *haridrā* (*haldi*), black pepper and elaichi. Astringent materials like the betelnut (*pugaphila*), and barks of trees like *mesaśṛṅgī, kapittha* and *kadamba* were also employed in making liquor.

The production system is only briefly described. Patanjali has *asuti* for distillery, *asavya* for the fermented mix, and *viniya* for the sediment left after distillation, while the vintner (and apparently also the seller) was a *saundika* (Puri, 1957, pp.89-115). The *Viṣṇu Purāṇa* calls the manufacturer of wine *maireyaka* and the seller *somavikrayī* (Dayal, 1982,pp. 93-104), and the *Amarakośa* has *svedanī* for an alcoholic still (Deshmukh, 1981, pp. 99-110). The *Arthaśāstra* has recipes for preparing various liquors, but the very terse language that is used makes their interpretation very subjective (Konow, 1975, pp. 60-63; Kangle, 1986, II, pp. 154-156; Agrawala, 1940, p. 291). It would appear that five elements could be varied. First was the raw material, which could be sugarcane juice, jaggery, honey, treacle, various sweet fruits, and cereals like rice and barley. Next, the period of fermentation is stated, in one instance, as being one month, six months or a year. Thirdly, the absence or use of distillation is frequently left unspecifed, except sometimes by inference through use of the adjective "strong" for the liquor. Fourthly, the liquor was frequently doctored with a sweetening agent, or with substances with either a distinctive fragrance, like flowers, or a distinctive flavour, like spices and astringent barks; confusion arises because these same materials

could be used even before fermentation, or added before distillation. Fifthly, there is the nature of the ferment itself. In one fairly clear statement in the *Arthaśāstra*, this is stated to consist of a *droṇa* or mashed *māsa* pulse, a third (or three parts, in another interpretation) of rice, and a *karṣa* portion of morata. But other ferments could be used, and one of these is a decoction made from a mixture of *mesaśṛṅgī* bark and long and black pappers; since such an extract is also a typical flavouring agent, there is room for uncertainty. Incidentally, a spice mixture is even now used in Punjab to make the spongy fermented snack, warri.

The actual recipes are therefore not unambiguous. *Praśannā* is made from twelve *āḍhakas* of flour with eight parts of water along with five *prasthas* of the ferment, to which could optimally be added the rind (another interpretation is bark) and fruit of *putraka* (alternative, *kramuka*). *Medaka* was made from half an *āḍhaka* of rice grains, one *droṇa* of water and three *prasthas* of ferment. An *āsava* in one reading employed one tula of woodapple fruit (*kapittha*), five *tulās* of treacle and a *prastha* of honey, all perhaps fermented together. In another, *āsava* is stated to be a mixture of "one *karṣa* each of cinnamon bark with *citraka*, *vilāṅgī* and *gajapippali*, and two *karṣas* each of *kramuka*, liquorice, *musta* and *lodhrā*; and one-tenth part of these is the formulation of the essence" which could mean that the larger quantities constituted the ferment, and the smaller the final flavouring. Maireya appears to have been a liquor disitilled from a spice-induced fermentation (a decoction of *meṣaśṛṅgī* bark, and two peppers); later the distillate was sweetened either using expensive honey or cheaper *guda* and *phanita* (Agrawala, 1949 p. 291), and flavoured with *triphala*, the well-known astringent ayurvedic mix of the chebulic myrobalan (*Terminalia Chebula*), the belleric myrobalan (*T.bellirica*) and the *amla* (*Emblica officianalis*). It was popular with royalty, and must have been an expensive drink.

Liquor in south India : Then as now, toddy was brewed in pots tied below incisions made in the spathes of palmyra palm fruits, to catch overnight the intensely sweet juice; this, by natural fermentation in the heat of the day, produced on alcoholic liquor with a strong odour. In the port town of Muziris, says the *Purāṇānūru* (Sreedhara Menon, 1979, pp. 121-126), "toddy flows like water". The practice of smearing the pots with lime to prevent fermentation is also old, since such pots turn up in excavations. The sweetest toddy was claimed to be produced in Kuttanād (Krishna Ayyar, 1966, p 31), now in Kerala. *Arrack* or distilled strong liquor was also to be had, a favourite of sailors (Srinivasa Iyengar, 1932, pp. 253-300). Liquor was also brewed from paddy, from rice, and from germinated grains in pots, stated (*Rasanyagam*, 1926, pp. 130-160) to yield "after two days and two nights a high-flavoured wine". The flavour of wine was stated to be improved by filling it in the hollows of stout bamboo stems, and burying them underground to mature (Srinivasa Iyengar, 1930, pp. 57-70). Toppi was the name of a home-brewed rice liquor (Ibid). Scented liquors were made for richer people by fermenting rice in the presence of fragrant flowers such as the *dhātakī* (*Kanakasabhai*, 1904, pp. 125-135). In mountain areas, wine was brewed from honey, and again matured underground before use . Italian wine was imported in the 1st and 2nd centuries AD for the use of royalty in characterisic two-handled amphorae; these have been found in large numbers at a Roman warehouse of the period excavated in Arikamedu near Pondicherry, with dregs of resinous material

two thousand years old still adhering to the bottom. A favourite drink, especially of women, was *munnir* ("triple liquid"), a mixture of tender (perhaps unfermented) palmyra juice, sugarcane juice and coconut water (Sreedhara Menon, 1979, pp. 121-126; Nilakantha Sastri, 1964, pp. 77—80). As many as 60 pure Tamil names for liquor occur in the early literature, indicating its widespread use and popularity. Vendors of liquor were called *tuvāsar*, *paḍuvar* (*paḍu* is one name for liquor), *palaiyār* (*pali* is another), *piliyar* (*pili* is yet another) and *saundiyār* (clearly a Sanskrit borrowal) (Srinivasa Iyengar, 1930, pp. 57-70).

Parched, puffed and parboiled rice

Parching : Even the *Ṛgveda* mentions *dhanāḥ*, which is beaten or parched barley, as well as *saktu* (the present *sattu*), which is the gritty brokens derived initially from parched barley grains, and later from rice (Prakash, Om, 1961, pp. 7-33). In the early stages, these grits were eaten as a solid ball (*piṇḍi*), or as a paste (*avalehika*), but by the time of Suśruta, *saktus* were being blended before consumption with acid fruits, grapes, ghee, sugar, *guḍa* and dilute honey (Prakash, Om, 1961, pp. 7-33). Parching of sprouted barley is recorded by Caraka, who also lists a variety of parched pulses (called *ulumbaḥ*) like *muṅg*, *masoor* and *maṭṭar* under the common name *bhriṣṭadhānya*. Other Sanskrit words for parching are *lajaḥ*, *pṛthuka* and *cipita* (Gode, 1948, p. 43); the last of these persists in *civda* or *cidva*, the fried and spiced snack made from parched rice. *Cūra* is the current term for beaten rice.

In south India, *aval* is still the word for beaten rice. The *Kuruntogai* (of about the 6th century AD) describes its manufacture by beating flat wet paddy, using a pestle of black heart-wood (Srinivasa Iyengar, 1932, pp. 253-300) and the *Perumpanurrupadai*, one of the Ten Songs (Rasanayagam, 1926, pp. 130-160), mentions aval itself.

Even though beaten or parched rice was available commercially both in north and south, its production appears to have been effected in the same pounding device as the one used domestically, first moistening the grains with water before flattening, and then parching them slightly afterwards on hot sand.

Puffing : The terms *missita* and *dhanidhaka* have been suggested as the Sanskrit equivalents of puffing of grains, but are believed to be uncertain in the context in which they occur. The Tamil term *pori* occurs in the Sangam literature of the 6th century AD (Srinivasa Iyengar, 1930, pp. 57-20), and its production was probably effected by the simple technique (even now current) of throwing handfuls of rice on very hot sand. The *cikpea* or *cana*, especially the large Kabuli variety (after it arrived in India) was also subject to puffing to give a porous, crunchy product; this could be ground into *besan* flour, which is the batter of choice all over India for making a variety of deep-fried snacks. Again production in volume could be achieved by merely multiplying the domestic puffing operation.

In south India, the term *pori*, still used for puffed rice, finds mention in the early Sangam literature (Srinivasa Iyengar, 1930, pp. 57-70). In the *Karuntogai*, it is a favourite food eaten with milk or as a sweet (Arokiaswami, 1972, p. 92).

Parboiling : Parboiled rice is called *pulangalarisi* in Tamil. It first occurs in the *Sirupan-arruppudai* of slightly late Sangam literature (Srinivasa Iyengar, 1930, pp. 57-70), but the means of production is not described. Perhaps it was the same technique now followed of soaking paddy in cold water for a few days, then boiling the water till the grain is soft, drying the grains in the sun, and then dehusking them either by pounding in a mortar or grinding between stones.

Oilseed processing

Oilseed crushing : A charred lump of sesame seed was found in Harappa (Piggott,1950, p.153), and carbonised *rai* (mustard) seeds in Chanhudaro (Visnu-Mittre, 1974, p. 3), so at least two oil- bearing seeds were known to the Harappans. They had copper frying pans with a lip (Mackay,1938,II, Pl.71,Item 42, Plate 82,Item 11) and small stone querns for grinding spices. The body fat of various animals and fish, and that of milk, was likewise available. Since all the elements were present, it is quite probable that frying of food was practised. Animal fats would have risen to the top on boiling any flesh in water. Whether vegetable oils were also obtained in this way, or in any other, is not known.

The *Ṛgveda* has two devices for crushing *soma*, the grinding stones or *grāvan*, and the mortar-and-pestle, *ulūkhala-musala*. When the *soma* sacrifice enlarged to include 16 priests, the crushing mortar may have grown in size as well. Large wooden grain pounders were of course also known. From such reduction devices could the oil press have had its origin, to judge by the terms employed for it, as hereafter discussed.

Sanskrit has *tila* for sesame seed and *taila* for its oil. From the time of the *Bhaviṣya Purāṇa* onwards, the composite word *taila* (or *tila*)-*pesana*-yantra stands for an oil press (Monier Williams, 1851, p. 549). *Tailikas* or oil millers find mention in Panini (Monier Williams, 1899, p.448), in the *Mahābhārata*, and *Arthaśāstra* (Shyamasastry, 1923, pp. 112-113) and in early Buddhist literature. Some sort of a wheel or circle (*cakra*) seems to have been involved, and the oil miller is called a *cakrin* in the *Amarakośa* (Deshmukh, 1981, pp. 99-110). Did the *tailika* walk round in a circle operating the unit, or was there an edge-runner of some kind? The use of animal power is never mentioned, and indeed is believed by some authorities to have never been employed in India for such traction before the Christian era (Roy and Bagchi,1983,(a), p.1). The *Arthaśāstra* has a list of oilseeds crushed (Shyamasastry, 1923, pp. 112-113), with their oil yields given as one-sixth, one-fifth and one-fourth; these are the sesame, linseed, safflower, *mahua*, *ingudi* (*Balanites aegyptiaca*), *neem*, *kapittha* and *kusamra* (identity uncertain). The oilcake is termed *ghanapinyaka*, the first-ever mention of the term *ghana* for an oilpress (Shyamasastry, 1923, pp. 112-113).

Terms used for an oilpress : Despite its lone use in the *Arthaśāstra*, all the evidence suggests that the word *ghana* moved from Prakrit into Sanskrit, when it next appears only in the *Ballalacarita* of 1510 AD (*Bhaṭ, Ānanda*). The words *ghranaka* appears once, and *ghanaka* several times, in inscriptions of the 5th century AD from Bengal (*Epigraphica Indica*, 1925/26, 18, 60), the 10th century AD from Gwalior (*Epigraphica Indica*, 1892, I, 162), and shortly thereafter in

Nashik (*Epigraphica Indica*, 1927/28, 19, 69). A Veraval inscription from Gujarat of 1264 AD has *ghamcika* for oil miller (*Epigraphica Indica*, 1961/62, 34, 141). All these have a Prakrit connotation. The origin of the word *ghana* itself can only be guessed at by a number of associations. *Grāva* is the Sanskrit grinding stone, *ghavan* is a stone mortar in Marathi, *ghaṭāni* a mill in Gujarati (Turner, 1966, p. 241), and *ghaṭānika* is a Sanskrit word for a heavy club (pestle), used in the *Rāmāyaṇa* (Yuddhakāṇḍa, 6. 1053) and *Matsya Purāṇa* (177. 11). *Ghana* for the oil press may represent an amalgam of such usages.

The other term commonly used for an oil press is *kolhu*. This again appears to be a Prakrit word, and it occurs in a Gwalior inscription of 933 AD in the Sanskritised form *kolhuka* (*Epigraphica Indica*, 1892, I, 154). Again its origin may be a complex amalgam of *ulūkhalika* (meaning the act of grinding), *khali* (oilcake), and *ukhli* and *okhli* (small mortars) (Platt, 1899, p. 106). The Tamil term *cekku* for the oilpress is by way of the Pali *cakka* (for *cakra*), a word which also gave rise to the common present term chakki for any circular millstone or pulley. The term first occurs in Tamil in the *Nāladiyār* (374) and the *Nālayira Thivya Prabhandam* (Thiruvaimozhi-7, 1 and 5) of the 7th or 8th centuries AD. However a reference occurs in the slightly earlier *Purananuru* (Verse 50,lines 6-7) to the froth (*nurai*) on the surface of oil extracted from sesame seed. This is a striking characteristic of oil when it first appears in a press, and strongly suggests that the oil pres was in use.

Actual oilpresses : Few old oilpresses have survived, being frequently made of wood in the past. A series of old stone crushing units have been brought together in Dwarka (Gujarat) from surrounding areas; though labelled as *soma* crushers, their design almost certainly points to their being oil-crushing units. One authority is of opinion that these units go back the first two centuries of the Christian era (Rao, S.R., Personal Communications). The same authority has also excavated *ghānis* from 6th century AD surroundings in Aihole (Bijapur District, Karnạtaka). A stone oilmill set up in Karnataka state by one Asakka-gavunda in 1145 AD with an inscription to this effect is stated to still surive (Gururajachar, 1974, p. 75). Till about a century ago, all commercial oil extraction in the country was effected in *ghānis*, with only regional variations in size and design.

Sugarcane processing

Crushing devices : Sugarcane crushers of the barrel type closely resemble the oil press, and the two share a common ancestry. This is hardly surprising since grinding, to effect the expulsion of a liquid (though of different viscosities) is of course the basic operation in both. Sugarcane pressing, like that of oilseeds, may also have arisen as an offshoot of the soma pounding operation.

In 1885 Grierson notes the similarity (Grierson 1926, pp. 44-60), and a few years George Watt states (Watt, 1972, IV, p. 153) that "the oilpress is identical with that used for the sugarcane but smaller in size". The Sanskrit word *ikṣu* for sugarcane gave rise to the later words *ikh* and *ukh*, as well as to *ukar* (a vessel for husking grain) and to *ukhli* or *okli*, a small mortar (Platt, 1899, p. 106). Both the terms *kolhu* and *ghāni* are used for the sugarcane press, except, as remarked by Grierson, that

the sugarmill is larger, has sloping sides (in contrast to the bottle-shaped pit of an oilpress) and carries no *reuti* or stirrer (which some though not all oil-presses do). In Marathi the term *khali* or *khalli* is used to denote substances as dissimilar as oilcake and sugar (Watt, 1972, VI, p. 502).

Much of what has been said about the evolution of the oilpress also applies therefore to the sugarcane press. The Buddhist literature mentions sugarcane juice being extracted with a machine (Prakash, Om, 1961, pp. 7-53), and in the Kuṣāṇa-Śaka period (75-300 AD), machine-extracted juice is declared to be inferior, presumably to the hand-extracted product. A Jain manuscript copied at Palam near Delhi in 1540 AD features a drawing of two oxen crushing sugarcane in a typical barrel-shaped *ghāni* (Daniels and Daniels, 1988, Drawing on p. 502).

The other sugarcane-crushing device is the roller mill with rotating cylinders, which has now all but superseded the *kolhu*. This seems to have originated from a similar roller device for removing seeds from cotton (Daniels and Daniels, 1988, Drawing on p. 502). The latter had itself replaced the rocking pin device on a flat board, worked by the hands or the feet, which had long been used for deseeding cotton (Watt, 1972, IV, p. 153) and is depicted in the Ajanta paintings (Roy and Bagchi,1986,(b),p.129). The sugarcane roller mill probably evolved only around 1500 AD, (Daniels and Daniels, 1988), and is therefore outside the period of the present article.

Sugar and its products: Harappan cities have yielded charcoal some *Saccharum* species, though whether this is the sugarcane is uncertain (Vishnu-Mittre, 1974, p. 3). The *kusara* of the *Ṛgveda* is thought to refer to it (Prakash, Om, 1961, pp.7-33). The chewing of *ikṣu*, which is certainly the sugarcane, is alluded to in *Atharvaveda*, while all the *Saṃhitās* of the *Yajurveda* mention the plant (Prakash, Om, 1961, pp. 7-33).

In the *Sūtra* literature, the thickening of sugarcane juice to give first *phanita*, and then *guḍa*, is noted. The next stage, that of rock sugar (*kāṇḍ*), finds mention in the writing cf Alexander's companions (Kosambi, 1975, p. 192), who describe "stones the colour of frankincense, sweeter than figs or honey". From Pundra or north Bengal came the superior variety of sugarcane, *pauṇḍraka*, and it is possible that sugar technologies were developed in Bengal or Gauda, from which Caraka derives the word *guḍa* (Prakash Om, 1961, pp. 251-252). In early Buddhist literature (Ibid, pp. 58-86), guda is described as being made from sugarcane juice using sugarcane flour (possible ground bagasse) and ashes, perhaps used for clarification. Mention in the Jain cannon of the word *matsyaṇḍikā* is intriguing, since later this material is defined (Ibid, pp. 132-167) as "globular in shape, like fish eggs"; either it is crystal sugar, or a confection of similar shape. Kautilya mentions all forms of sugar, upto *śarkara* or granulated sugar, as does Patanjali in the mid-2nd century BC (Ibid, pp. 87-101). *Śarkara* derives from grit or gravel. and it has been remarked (Kosambi, 1975, p. 123) that the word does not have a "Sanskrit appearance". China has claimed precedence in crystal sugar production, to which the use of the term chini for sugar would lend support. But the visit of a team from China to the emperor Harsa in the 7th century AD to learn the technique of sugar production is also on record.

South India obtained a large part of its jaggery from the fresh juice of the spathe of the palmyra palm (and Bengal from the trunk of the date palm), using slaked lime to prevent its fermentation (*Rasanayagam*, 1926, pp. 130-160). No crushing is involved, and the juice is simply boiled down and when thick poured into coconut halves to set to jaggery or vellam, a word mentioned in the earliest literature. Waving tassels of the sugarcane ("like spears") are also frequently referred to, and sugarcane processing is mentioned (Gode, 1948, p. 43), but products of the sugarcane seem to have been of lesser importance in south India, even till recent times. Cane sugar crystals have an old name, ayir (also meaning gravel) (Srinivasa Iyengar, 1930, pp. 57-70), but are commonly called śakkarai, a word which is clearly of Sanskrit origin.

Honey

Types and Usages : The Bhimbetka prehistoric cave paintings show men dispoiling the hives of bees on rocks perhaps 6,000 years ago (Dave, 1954, 1955). The *Ṛgveda* considered that honey from small bees (*śāragava*) was superior to those from large ones (*āraṅgara*) (Prakash, Om, 1961, pp. 7-33). In later literature, three kinds of bees and honey are frequently referred to (Gopal, 1969, p. 255). The first is *makṣika*, used for both the common honey bee and its honey, which is by far the most important kind. Next is the *bhramara*, a large black bee giving a honey of the same name that was believed to be difficult to digest. The third was the small, black *kṣudra* bee giving *ksaudra* honey, the only one mentioned in the *Arthaśāstra*. The fourth one mentioned by Caraka is *pauttika* honey from the *puṭṭika* bee, which the *Amarakośa* defines as being a very small black bee resembling an ant. Suśruta has four more types of honey, termed *catra*, *arghya*, *auddālika*, and *dala*, which have all been identified in modern terms (Gopal, 1969, p. 255). A Kashmiri work of the 9th century AD has several words for bee clusters,like *indindhira*, *dvivepa* and *bhṛṅga* (Sh^stri,1975,p.204)

Honey was considered stimulating, and therefore frequently banned to students, widows, those under a restrictive vow, and the like (Prakash, Om 1961, pp. 132-167). It was always pure even when taken out from the bowl of a *mleccha*, and was a constituent of *madhuparka* used to welcome guests, and a recommended food item during the rainy season (Ibid). Jains were strictly forbidden the use of honey (one of the 22 "uneatables") since its collection was believed to entail loss of bee life (Sanghave, 1980, p. 259; Kannoomal, 1916, p. 78).

Production : In Vedic times, the Rbhu brothers were stated to have built artificial hives of reeds and straw, secured honey sections from a natural hive, and fixed them in the prepared hive (Dave, 1954, 1955). When a swarm had settled in, a year was allowed to elapse before four combs only were removed and the rest left in. Knowledge of bee-keeping was kept secret, and the Vedic saint Dadhyang was beheaded when he taught the Asvins his skill. In later times hives were kept in logs or pots in a horizontal position, or on four-legged stools, or in a wall. In Kashmir the latter procedure is still in use, with detachable ends. When ready, both ends are removed, the bees are gently smoked away and a few combs removed; when the ends are replaced, the swarm soon returns.

The *Mahābhārata* has references to bee gardens, apiary keepers and pollen-yielding plants, suggesting some degree of commercialisation (Dave, 1954, 1955). The *Mahāvaṃśa* has a story of three brothers, two of whom collected honey for sale by the third (Gopal, 1969, p. 255). Generally collectors were forest dwellers, both in the north and south of India, who sold or bartered their valuable produce. The *Harṣacarita* mentions beeswax by the expressive term *madhucchiṣṭa* (Ibid).

Salt

Types and uses: Salt is not mentioned in the *Ṛgveda*, but thereafter many types are recorded. Five kinds, first mentioned in the *Vinaya Piṭaka* (Prakash, Om, 1961, pp. 58-86), and later by Caraka (Ibid), are the more important. These are rock salt, sea salt, *viḍa*, *audvida* (probably the same as the *udhbedaga* of Kauṭilya) and *sauvarcala*. Suśruta has nine others (Ibid), most of which appear to be other mineral salts of sodium and potassium. Kauṭilya mentions "salt from the Sindhu country", but whether any of the other special regional salts now recognised were known cannot be ascertained. These include the kurkutch of Maharashtra and Gujarat, *kuppa* and *baragara* (in large cubes) from Gujarat, *paṅga* of West Bengal, the pink *kyar* and *resta* of Rajasthan, and the *mapi* or *vajni* of the east coast. These contain impurities in varying proportions which alter their taste and colour.

From *Sūtra* times, salty foods were not permitted to students, widows and newly-married couples for three days (Ibid). Use of *viḍa* and black salt was interdicted during a *śrāddha* (Ibid, pp. 102-131). Sea salt was always rated superior to other salts as a food (Ibid, pp. 132-167).

Production and sale: Details of production are lacking, especially for varieties other than sea salt. The latter was probably obtained, as it is now, by solar evaporation in long shallow beds along the shore, fed by the incoming tide; the crystallised salt was simply raked off. In Kauṭilya's account, salt manufacture was scrutinised by a special superintendent, the *lavanādhyakṣa* and carried out under a system of licences for which either a fixed fee was paid, or a share of output retained (Monahan,1924,p.54). Salt that was received by government as its share was sold by the superintendent, profit being ensured by the difference of 5 percent between the royal measure and the common measure. One-sixth of all imported salt went to the king, and was sold by the superintendent to the public, with a profit made both in measuring the quantity and in selling it.

Salt in south India: The Sangam literature of the first six centuries AD is quite forthcoming. Activities of people living in different localities are set down, and this includes salt-making in the coastal littoral. Mention is made (*Rasanayagam*, 1926, pp. 130-160; Srinivasa Iyengar, 1932, pp. 253-300) of "hearths of stones left by the salt vendors", and of "white salt manufactured in clayey beds", certainly by evaporation. Salt must have been extensively made, and five names are recorded for salt beds, namely *nanuguppalam*, *alkkar*, *uvarkkalam*, *uvalagam* and *kazhi* (Srinivasa Iyengar, 1930, pp. 57-70). The more important places of manufacture were Markanam, Kanyakumari, Variyur, Aythurai and Bapatla (Ibid). No varieties other than sea salt seem to be recorded. Salt sellers went round villages with headloads crying out the price, (Rasanayagam, 1926, pp. 130-160), and salt was transported across the peninsula in carts by producers moving about with their

families (Arokiaswami, 1972). Salt was exchanged for various other commodities like rice, and both salt and honey were principal measures of value (Pillay, 1975, p.284).

Cold water and ice

Evaporative cooling in really porous clay jars was a time- honoured technique of cooling water. The use of saltpetre for cooling water was apparently introduced by Akbar, according to Abul Fazl. A scene from the *Harṣacarita*, describing the ministrations to the dying father of the emperor in Kannauj (Upadhyaya, 1947, p. 216), refers to whey for a gargle being kept "in a new vessel besmeared with wet clay". The same passage states that "buttermilk was freezing in pails packed with ice". This could have been brought from the Himalayan heights by river and land in relays, as was later the practice of Mughal emperors. However the making of ice may not have been unknown in the area, to judge by a description recorded in Allahabad in 1775 by a resident English scientist (Dharampal, 1971, p. 219). During three months of winter when the temperature was close to, but never below, freezing point, boiled water was poured a couple of centimetres deep into small shallow porous vessels and the latter placed in long, shallow pits, well insulated at the bottom and sides, that were scooped out in quiet and windless surroundings. Overnight ice would form, sometimes all the way through, and this was collected and kept in insulated storage for use all the year round.

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Veterinary Science

S.K. KALRA

Krishnaswamy has compiled fairly large and valuable information on ancient veterinary science literature in India, while the search for indigenous drugs has been forwarded by others (Perera, 1940, Singh and Kohli, 1955).

A part of Śālihotra's *Aśvaśāstra* (vide Apte, M.S), *Jātakapari jātaka*, *Śukranīti* and *Jayadatta's Aśvavaidyakam* are now available in English translation and my observations are mainly based on these works. A symposium on 'Veterinary Literature in Ancient India', was also organised in 1986 (IJHS, 22(21), 93-169), which also serves as important source material.

The ancient system of Indian medicine is termed *Ayurveda* (*Gavyāyurveda* for cattle, *Hasthyāyurveda* for elephants and *Aśvāyurveda* for equines). It is confined within the limits of Tridoṣa theory of physiopathology (*Vāta*, *Pitta* and *Kapha*) and Pañcaśīla theory of pharmacy (five principles of matter/drugs viz *Rasa*, *Guṇa*, *Vīrya*, *Vipāka* and *Prabhāva*) (Sircar, 1982), and these concepts are still require to be updated in current timeframe.

Ayurveda possibly remained outside the influence of Renaissance in Europe. Scientific contents in Indian veterinary science books remained particularly hidden, and their features have found no mention in modern textbooks.

Ethnology

Morgan developed a Principle of Comparative Method for interpreting ancient history from the conditions of ancient tribes, while conducting his studies among American aboriginals. Satija (1987) has likewise tried to put on record the Indian folk veterinary practices, using comparative methods, so that their origin may be placed in historical frame of development.

Primitive human societies in various geographical regions have been using plants and plant products for various remedies. A large number of these folk prescriptions are endemic to certain areas and have survived through ages, from generation to generation through the word of mouth. They do not exist as written

knowledge. In aboriginals, who reside in remote areas lacking organized medical infrastructure, dependence on their endemic prescriptions is exclusive.

A list of ailments for which folk prescriptions are available is given in *Table I*. The *Table 2* gives names of plants used in same disease conditions by different tribes. Method of agreement in terms of disease conditions calls for a study of common useful factors in various plants used.

Table 1 — Disease conditions for folk treatment

Medicinal Problems	Surgical Problem	Gynaecological Problems
Indigestion	Wound	Hypogalactia
Colic	Maggot wound	Agalactia
Diarrhoea	Inflammation of udder	Anoestrus
Retention of urine		Retention of placenta
Haemoglobinurea	Lameness	Prolapse of vagina
Pica	Broken limb/fracture	Leucorrhoea
Blindness	Dislocation of limb	
Dropsy	Gangrene of tail	
Insect bite	Conjunctivitis	
Allergy		
Rheumatism		
Convulsions		
Eczema		
Mange		
Lice and Ticks		
Stomach worms		
Mastitis		
Pneumonia		
Anthrax		
Haemorrhagic septicaemia		
Black quarter		
Actinobacillosis		
Foot and Mouth Disease		
Rinderpest		
Rabies		

Table 2 — Plants used for same disease condition in different ethnic groups in India

Disease condition	Hisar area	Bastar area	Kumaon area	Santhal area	Ladakh area
Diarrhoea	*Vernonia anthelmintica* (kaliziri) *Acacia arabica* (kikkar)	–	*Bergenia ligutata* (pakhanbed)	–	–
Internal worms	–	*Mucuna prurita* (kawanch)	*Brassica rugosa* (rai) (rai)	–	–
Indigestion	*Curcuma zeodaria* (kacuri)	–	–	–	*Prangos pabularia*
To induce lactation	*Citrus aurantifolia* (nibu)	–	*Brassica gugosa*	–	- do -
Fractures	–	*Coxylosperm um religiosum Nyctanthes arbortristes* (harsinghar)	–	Abrus	–
Leucorrhoea	*Caesalpinia crista*	–	*Aesculus indica*	–	–

Written Literature

Reviewing the sources of ancient literature on veterinary sciences, Garg (1987) refers to several manuscripts, their authors, availability and possible historicity.

Among the ancient authors are found the names of Śālihotra, Pālakāpya, Rājaputra, Vaiśampāyaṇa, Vyāsa, Nakula, Sahadeva, Garga, Mṛgasarmā, Bṛhaspati, Nārada, Gaṇa, Jayadatta Sūri, Dinapathi, Malladeva Paṇḍita, Siṃhadatta, Nala, Vatsya, Śukra, Manu, Kauṭilya and Paraśara ; and among the authors of later date come Jayadeva, King Indusena, Bhoj, Sāraṅgadhara, Somesvara, Vahada, Bāsavamantri, Girvana, Yuddhavikrama, Viśvanath Vajpaye, Śivarāma Bhupati, Dipaṅkar, and the poet Rudradeva. Each one of them is reported to have contributed a book on veterinary science; many of these works are now lost either in part or in full but some fragments of a few of them are still available here and there, in libraries and oriental institutions. Of all the authors mentioned, names of Salihotra as the authority on horses, and Pālakāpya on elephants stand pre-eminent.

Śālihotra is said to have lived in Salutar, a country near Gandhara, the modern Kandahar. Manuscript entitled *Aśvayurveda Siddhayoga Saṃgraha* (P.P.S. No 11251 and Burnell Catalogue No 12302, S.M. Library, Tanjore) is ascribed to Salihotra, who seems to be the foremost and indeed, the father of all Indian authors on veterinary science. Antiquity of Śālihotra may be inferred from the fact that he has been quoted by Hemadri in *Vratakāṇḍa*. Some portions from his work have been quoted in the *Agni Purāṇa*, the *Matsya Purāṇa* and *Garuḍa Purāṇa*. This tends to prove that Śālihotra's work is pre-Puranic.

Śālihotra is again mentioned in his commentary called *Tikasarvasya* of Nāmaliṅgānuśāsana, the dictionary of Amarsiṃha. Moreover, many other authors on horses, who are equally antique and authentic began their writings by paying respect to Śālihotra as the originator of the science.

Śālihotra's work on horses appears to be a very comprehensive one, consisting of eight parts (16,000 ślokas in 120 chapters) dealing with practical farriery. It is a complete guide to the science of horses, dealing with their breeding, training, feeding, watering, stabling, grooming, and their care in health and disease; with an elaborate description of several diseases they are susceptible to, and their treatment. The entire work is not extant. A portion of it is available at Tanjore, and other portions in stray parts are reported from Calcutta, Lucknow, Baroda, and Nepal.

Next in importance is *Pālakāpya*, the first and most ancient author on Elephantology. Edgarton, Professor of Sanskrit, Yale University, USA, remarks in the introduction to his book 'The Elephant Lore of the Hindu', 'All known texts agree in attributing the founding of scientific elephantology to a mythical sage, Pālakāpya. They likewise agree in making this elephant lore to an apparently mythical Romāpada, the king of Aṅgas, whose name is not otherwise known' etc. The name of Romāpada, the king of Aṅgas, occur in Bālakāṇḍa of the great epic *Rāmāyaṇa*, where it is stated that king Daśaratha had invited to Ayodhya the sage Ṛṣyaśṛṅga, the son-in-law of Romāpada. This points to the indication that Pālakāpya's book on elephantology must be older than epic period.

The works of other ancient persons, their availability, probable period and source is compiled in *Table 3*. The works of authors on Veterinary Sciences in ancient India can be classified in three periods as below:

The Vedic Period: Atharvaveda contains treatise on medicine and some information on veterinary science belongs to this period.

Epic Period: During this period Ayurveda or the sciences of knowledge of life came to existence. To this period Śālihotra, Pālakāpya, Rājputra, Mṛgaśarmā, etc belonged. In the age of Mahābhārata, Nakula and Sahadeva flourished.

Period of Purāṇa and Sūtra : Several puranas wherein copious information on veterinary matters is available are Matsya, Garuḍa, Agni, Brahmāṇḍa, Viṣṇu and Liṅga Purāṇas. Several books on polity like *Manu Saṃhitā*, Kauṭilya's *Arthaśāstra*, *Bṛhaspati Mātā*, *Parāśara Saṃhitā* and *Śukranīti*, where much information on veterinary matters exists, belong to this period.

Table 3 — Ancient Veterinary Literature and related information

Author	Work/Book	Period	Availability with source/comment
Not known	*Atharvaveda*	Vedic	*Available, contains some information on veterinary matters
Śālihotra	*Aśvāyurveda Siddhayoga Saṃgraha*	Epic	Some portion of original work available in Sarsvati Mahal Library, Tanjore. Other parts available in Kashmir, Nepal, Calcutta, Lucknow, Baroda English translation - 2 copies available in British Museum, London and Berlin Library. Translated in Arabic, Kitab-ul-Vitrat by Saiyad Abdulla Khan Feroz Jung. Translated in Tibetan, exists in Tibetan grab in encyclopaedia called Tangyur
Pālakāpya	*Hasthyāurveda*	Epic (Rāmāyaṇa)	*Available
Rājaputra?	Epic		Book not available, but search among available manuscripts in Kashmir, Nepal, and amongst Jains of Gujarat may be useful
Nakul	*Vaidyaka*	Epic	Not available
	Sarvasva, Aśva Cikitsā	(Mahābhārata) -do-	*Available
Sahadeva	*Vyādisindhu Vimardana*	Epic (Mahābhārata)	Not available
Bṛhaspati	*Bṛhaspatimātā*	Epic	Available in Government Oriental Manuscript Library, Madras
Vyāsa (Vaiśampāyaṇa)	*Aśvāyurveda, Sāra Sindhu, Gajaśāstram, Gajalakṣaṇa, Cikitsā*	Epic	Available in S.M. Library, Tanjore
Garga	Work on treatment of horses referred to in book on medical science *Pryoga Ratnākara* and in *Matsya Purāṇa*	Epic	Palm-leaf manuscript available in Ravanshaw Library, Cuttack (Orissa)

contd.

(Contd. Table 3)

Author	Work/Book	Period	Availability with source/comment
Gana	*Aśvāyurveda, Siddhayoga* Saṃgraha	Epic	Available in S.M. Library, Tanjore Government Oriental Library, Madras
Jayadatta Suri	Aśvavaidyakam	Epic	Available in print
Malladeva Paṇḍita	Aśvāyurveda Sāra Sindhu	Epic	Available in S.M. Library, Tanjore
Bāsava mantri	Śivatattva Ratnākara	?	? Gives information about fowl, sheep, goat, dogs, serpents
?	Purāṇas Matsya, Garuḍa, Agni, Brahmāṇḍa, Viṣṇu Liṅga	Purāṇic	Valuable information on veterinary matters exists in all of them
Śukra	Śukranītisāra	12 or 14 A.D.	Availability not exactly known
Cāṇakya	Kauṭilya Arthaśāstra	Mauryan	Availability not specified
Manu	Manu Saṃhitā Parāśara Saṃhitā	200 B.C. to 200 A.D.	Laws of Manu, Extant
Kālidāsa	Raghuvaṃśam	5th century	Gives description of nature. Also gives some veterinary information.

* Exact place/ library or availability not specified.

Nature and Extent of Information

Based on limited verterinary science literature available in English, possibilities have been searched to relate it to modern veterinary science literature (Mandokhot, 1987, Kalra, 1987). The literature screened in this context is *Aśvavaidyakam, Aśvasastra*, and *Śukranīti*, in the form available.

Scope of information content

In terms of species covered, the maximum information pertains to equines. Other species covered are elephants and bovines, besides camels.

Owing to several qualities, elephants were used like modern tanks in wars by the kings in ancient India. Perhaps nowhere else worldover, so rich information is available on elephants as in India. According to Krishnaswami, Hasthyāyurveda by Pālakāpya can serve as a foundation book for further build up. It is supposed to contain well classified, varied and interesting information. Under the heading of fevers in chapter 9 of part 1, and 'wasting diseases' in chapter 40 of part 2, it is supposed to contain information on tuberculosis, perhaps the first record of the disease.

Study of book '*Aśvavaidyakam*' reveals that not only the classification of its contents into chapters has been on scientific lines, comparable to those in modern books, rather the practice of reviewing the literature was also followed. Names of sages/gods reviewed are Śaṅkar, Brhamā, Śālihotra, Nakula and Suśruta.

Information on camels, whatever available, should also be exclusive, because this species was domesticated in Indian subcontinent.

The *Aśvavaidyakam* consists of 1,800 slokas distributed in 68 chapters, covering right from parts of body (Anatomy) to management, nutrition, breeding and diseases.

Parts of body

Importance of parts of body is given in sloka 1 in chapter 2 of *Aśvavaidyakam*, which reads 'The fool, who does not know the sign of horse's body in detail, does not know the sign of horse nor the treatment of their diseases'. In fact this fundamental aspect is given in the very second chapter, after devoting first chapter to the scope and purpose of the book (*Uddeśaḥ*). Different parts of body are described in precise topological sequence starting from the mouth to the back dorsally, downward upto the sole, and then ventrally.

Our ancients were equally concerned with measurements of body parts in the normal state of health. For this parameter, they had evolved a methodology suited to the timeframe, when education was imparted through recitation of slokas. Slokas 145-147 of *Śukranīti* reads 'If an image is to be made, the appropriate pattern should always be placed in front. No image can be made without a model. So the artist should frame the limbs after meditating on the horse in the manner indicated'.

In the ślokas 85-144 of *Śukranīti*, comparative dimensions of body parts of horse are given; ślokas 79-82 deals with elephants and 299-300 with bulls. Unit of measurements are Angula or Finger's width called *Muska* (4 *aṅgulas*), Cubit (length of arm) and length of face. Detail of measurements cover lengths, widths, heights, 'circumferences and spaces and they correspond well to what is given in modern anatomy books.

Thumb of rule for dimensions of bulls are 'Circumferences of belly is four times that of face, the height together with hump is three times the face and length is 3.5 times the face'.

Control of Animals Including training

A fairly good account of the requirements of horses in terms of action, pace and speed is given in chapter 3 of *Aśvavaidyakam*. śloka 93 reads 'A chearful horse runs swiftly, lifting the legs high up as if they touched burning coals'. A good horse should be able to cover 400 cubits in 16 fillips. If it covers 380 or 360 cubits, the horse is medium or lowest, respectively.

While horses have been classified into various breeds according to the speed (besides other criterion), importance of good training is nonetheless, highlighted. Citation from *Magasthene's Indika* reveals that the training of horses was imparted during Mauryan period also. 'Those trained from boyhood can control horse with bit and bridle and can make them move at a measured pace and in a straight course.

Trainers train them by forcing them to gallop round and round in a ring. Such trainers have strong hand and thorough knowledge of horses. They could control with ease a team of four high mettled steeds when whorling round a circle'.

Chapter 7 of *Aśvavaidyakam* is devoted to the rules for training horses (*Vahan Vidhāne*), under following heads:

i. Classes of horses (*Vipraditad vahana vivaraṇam*)
ii. Nature and strength of horses and their training (*Satvaśakititad vahana vivaraṇam*)
iii. Description of training ground (*Raṅga bhūmi vivaraṇam*)
iv. Merits and Demerits of a rider (*Doṣa guṇa taraṅga vivaraṇam*)
v. Duties of a rider (*Sadi kārya vivaraṇam*)

Modern books on horses describe five types of gaits of horses, all of which are provided both in *Śukranīti* as well as *Aśvavaidyakam*. In Table 4 is given the terminology used for various types of gaits.

Table 4 — Gaits of Horses Terminology in

Current literature	Asvavaidyakam	Śukranīti (Śloka no)
Full gallop	Vikrama	Dhārā (289) Arkaṇḍita (292)
Cantre	Purānkaṇṭhi	Recita/Rectia (293)
Amble	Dhārā	Pluta (294)
Trot	Pluta	Dhauritaka (295-296)
Fast walking	Tvarita	Valgita

Judging age of animals

Śukranīti demarcates infancy from middle age with replacement of naval teeth. Horses have six lower incisors. In the first year, their colour is milky white, which turns muddy in second year. In the third, fourth and fifth years respectively, central, lateral and corner pairs get replaced by permanent teeth. With advancing age, permanent teeth acquire dots, whose colour changes in order from Black (*Kālikā*), Yellow (*Hārini*), White (*Śukla*), Glassy (*Kāśa*) to Honey or Chocolate (*Makṣika*). Finally, Conchshell holes (*Śaṅkha*) appear followed by final shedding.

Besides the above changes in teeth, horses having attained full age also acquire three circular rows on upper lips.

Similar information on judging age of bulls is also given.

Breeding

Elephants were allowed to breed in natural habitat and trapped, as is the practice in present day also. In general the elephants with long cheeks, eyes, brows and

forehead, swiftest speed and with auspicious marks on the body were considered to be the best. They were classified in four categories (*Table 5*).

Table 5 — Classification of elephants

Class	Body signs	Measurements in cubits		
		Height	Length	Circumferenc
Bhadra	Honey coloured, strong well formed tusk, round and fat body, good face, and excellent limbs	7	8	10
Māndra	Fat belly, lion like eyes thick skin, throat and trunk, medium limbs and a long body	6	7-8	9
Mṛga	Small or short throat, tusk, ears and trunk, big eyes and very short lips and genital organs and is dwarf	5	6-7	8
Miśra	Mixture of above characteristics			

Cattle breeding apparently was one of the important aspects of animal husbandry practices in ancient India. The administrative authorities appeared to be fully aware of its importance. The king was enjoined to preserve the breed of cattle in the country and a government officer called Superintendent of Cattle was entrusted with the exclusive task of supervising the livestock in the country, keeping census and ensuring their proper breeding and rearing. He was also supposed to maintain a record (register) classifying the cattle as male calves, steers, tamable cows, draught oxen, yoke and breeding bulls, cattle fit for slaughter, buffaloes, female calves, heifers, pregnant cows, milch kine, barren cattle etc.

The criteria detailed for selection of bulls for breeding purposes can be grouped to indicate vigour, health, body conformation and freedom from congenital defects/infections as shown in *Table 6*. It may be noticed that these empirical criteria are valid even in the present day context when claim is made to have comprehensive understanding of the selection attributes. Information is also available about the particulars of the time of the service and the ratio of the males to the females to be maintained in the herd of cows and buffaloes. Inclusion of four bulls in every herd of ten cows or buffaloes had been recommended. In the case of cows the colour of pigment of skin was considered to be the index of nutritive value of milk. The milk of black cows was considered to be the most nutritive, of the red next to it, and that of white to be the least.

Table 6 — Correspondence of modern equivalent to the referred selection criteria for bulls

Vigour	Thundering roar, walk like infuriated elephant, capability to protect the herd
Health	Shining eyes, neither wicked nor idle
Genetic Attributes	History of coming from milch cow with young ones living and not deficient of any limb
Conformation of body	Well formed body, broad back, elevated shoulders, soft and straight tail with big tuft of hair, tender cheek, sharp horn, high stature hump

For Horses, detailed description regarding various body signs like colour and lustre of the body, marks and whorls present on the body, voice, odour, congenital habits, general appearance, body size, gait and motion are available. These body signs have been linked with desirability or undesirability of the animals for auspicious reasons and luck through fulfilment of desires for war/battle and prosperity and success. In reference to present day knowledge, the utility of many of body signs described may be obsolete. Śālihotra classified horses as good, medium or inferior, on the basis of their height, length etc. (*Table 7*).

Table 7 — Classification of horses according to measurements

	Measurements in cubits (C), fingers (F)		
	Good	Medium	*Adhama* or Inferior
Height from hoof to withers/girth	4 C	3.5 C	3 C
Length from outer canthus of the eye to the root of tail	7.5 C	6 C	6 C
Shank	16 F	14 F	12 F
Face, breast, loins	32 F	30 F	28 F
Hoof	7 F	6 F	4 F

The good, medium and inferior breeds of horses were also recognised on the basis of their Janamadeśa, i.e. the country of their origin. The good horses were supposed to come from deśa (country) like Jajikaḥ (Arab), Pārasikaḥ (Persia), Kekkana (Konkana, a strip of land between Sahyādri and the sea) and from Prastha (not yet identified). The horses born in *Tura* (Turkey), *Kira* (Kashmir), *Bhuruṣṭa* (Bhrgukaccha, probably modern Bharouch in Maharashtra), *Bhāṇda* (not identified), the hills of Sindhu and Sārasvata, were considered medium. Those from Sambhala (Sambal Moradabad, also a name of Birdhist Bactriana), Kusa (possibly Tamilnadu) and Jaṭādeśa (not identified) were considered to be inferior.

Judgement of Prognosis

Eye symptoms of horses as revealed in Śālihotra's *Aśvaśāstra* is also an interesting piece of information. Terminology used is *Vāta*, *Pīta* and *Kapha*. As a background information, Sircar represents Vata as Nervous disorders, Pīta as Metabolic disorders and *Kapha* as organic trouble to tissues. Śālihotra recommends that the eyes should be fully opened for examination at the inner canthus. Index to prognosis from eye symptoms is given in *Table 8*. Other aspects dealt in *Asvavaidyakam* are given in *Table 9*.

Table 8 — Prognosis of horses from eye symptoms

Dry and glassy	Vāta
Yellow and dark pink	Pīta
White and watery	Kapha
Dark yellow	Fever
Peticeae	Death in 6 months
Bluish tint and discharge like honey	Death in 2 months
Conjunctiva blood diseased by Pita, Lachrymation is of blood tint and conjunctiva is pale	Immediate death
Bluish yellow tint in conjunctiva	Death in 3 months
Streaks of various colours on conjunctiva	particularly during cold season
Watery golden discharge	Death in 10 months
Conjunctiva bluish tint	*Vāta*—Death in 3 months
Pita affected animals	eyes acquire a colour similar to that of *Curcuma longum* (Halakuṇḍa)
Appearance of colour on conjunctiva in early part of a season	Death in 7 days
Pita affected animals one eye blue and eyelid inside is dark black	Death in 1 month
Inner canthus of both the eyes dark red or dry or dots similar to those on peacock feathers, black or disquamation of epithelium on different parts of eyes	Immediate death

Table 9 — Aspects dealt with in unavailable parts of Aśvavaidyakam

Chapter	Aspects dealt
8	Treatment of sterility
9	Pregnancy
10	Nursing of newborn and its mother
11	Weights and measures
13	Housing and rearing according to seasons

contd.

(Contd. Table 9)

Chapter	Aspects dealt
14	Cauterisation
15, 16	Enema with medicinal extracts/oleogenous drugs
17	Drug administration through nose
18	Modes of sweating
19	Oleogenous drenches
20, 21	Preparation of medicated oils and ghees
22	Care of animals after exercise
23	Three signs of prognosticating deaths
24 - 68	Glanders (*Mṛgroga*), diseases due to variation of *Vāta*, Diseases in order from mouth and eyes onwards, well known diseases of eyes viz., Opacity (*Kācam*), Tumors (*Pracaram*), Conjunctivitis (*Raktam*), formation of membrane on the eyes (*Paṭalam*), Filaria oculi(*Muñja jalam*), diseases of brain arising from Vāyu, Pīta and Kapha and combination of them (*Sannipāta*), excessive pressure of blood.

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Inland Fisheries

A.K. SHARMA and B.R. SINGH

Literally, fishery means business of catching fish or industry of fishing. Fishery concerns itself with the effect of commercial fishing on fish population and to acquiring adequate knowledge of interrelationships of various species of fish to each other, to other animal life and the environment. Evidences of fisheries life in the Indus valley and the adjoining areas of Sind, Punjab and Baluchistan have been brought out by a careful study of the actual remains of fish and fish hooks found in Mohenjodaro, Harappa, Amri, Nal, Nundara and Rupar cultures. Seals, amulets, fingurines, paintings on the pottery and other wares have been engraved with fish designs.

Our knowledge of history of man's earliest culture is almost entirely restricted to the stone tools that have been preserved. The concept of three Ages viz., Stone, Bronze and Iron was first given by the Danish archaeologist, Vedel-Simonsen in 1813. The Stone Age was later split up into Palaeolithic, Mesolithic and Neolithic cultures.

The stone-age people hunted for the wild animals that lived in jungles along the rivers and lakes. Apart from the wild animals, fish found in lakes and rivers also formed the source of food for them.

Hunting, food gathering Mesolithic people used microliths to point and barb their arrows and also as knives and scrappers. Microliths have been found in large quantities from the Indian subcontinent. Sankalia (1962) pointed out that these microliths must have been made by people for the purpose of hunting and fishing as they lived in temporary camps near the river banks or sea-coasts. Arrow heads made of stone indicate that they used bows and arrows for hunting and fishing.

The Neolithic period in India is difficult to determine. The transition from hunting in the Palaeolithic to farming way of life in the Neolithic culture took place gradually.

From the pre-Harappan peasant communities of Baluchistan, some interesting pottery remains with fish paintings have been excavated from Nal (Jhalwan division of Kotat State in Baluchistan). The Nal valley in Baluchistan is about 30 miles long and seven miles broad. It lies in latitude 17°40′ North, longitude 60°48′ East and is nearly 3834 feet above sea level. Data available on fish paintings from Nal have been brought together and discussed by Hora (1955). From the fish decorations on Nal pottery, there can be little doubt about their generic identification except for a pair of fishes painted on Vase No. 142 of Hargreave's (1929) list. However, their identification at the species level cannot be said to be certain. From the decorations of the hill stream fishes on Nal pottery, it is evident that fast-running clear streams existed in its vicinity. Except for the genus *Cyprinion*, fishes of the other seven genera out of eight painted (Garra, Labeo, Crossochilus, Tor, Nemachilus Botia, Glyptothorax) are well represented in the perennial streams of Himalayas.

Since no fishing implements have been excavated from Nal, it can be inferred that the usual methods of fishing by nets and angling were not applicable to torrential streams. Then the methods of fishing must have been by damming small channels and allowing them to run dry or by poisoning the pools with certain plant juices which stupefy the fish and cause them to float on the water surface. Such methods of fishing though considered illegal, are still practiced at many places in the hills.

The Indus valley civilisation or the Harappan culture is older than the chalcolithic culture. The Harappans produced their own characteristic fish hooks, pottery and seals.

Fish remains obtained from the excavation at Mohenjodaro (Sewell, 1947), Harappa (Prashad, 1936), Rupar I, Ranjpur I and Lothal belonging to Indus valley culture indicate the following types :

Mohenjodaro — Rita-rita, Wallago, Arius sp. and Carp bones.

Harappa — Rita rita and remains of a Carp.

Vats (1940) has pointed out a fish toy discovered from Harappa.

The art of angling seems to have reached a high level of perfection in the Indus valley civilisation. Apart from the Indus valley, no other excavated or explored site has yet brought to light any specimen of fish hook in India. At the same time, the aboriginal tribes of India appear to be ignorant of the method of fishing by hooks.

The Maria Gonds (Grigson, 1938) use horns as hooks to catch fish. The Sakai of Malay-Peninsula (Skeat and Blagden, 1906) use curved thorns of rattan (Calammus).as fish hooks. Fishing by gorge-hooks is, however, practised in the case of Koi (Anabas) fishes in paddy fields of East Bengal. It is probably one of the local indigenous methods as it is not prevalent in West Bengal.

The fish hooks of the Indus valley can be classified into two main types : (1) Barbed, and (2) Unbarbed.

All the 16 specimens of Mohenjodaro are barbed. Of the Chanhudaro finds, 3 are barbed and 4 are unbarbed. The solitary specimens from Harappa is unbarbed. The paucity of fish-hooks at Harappa indicates that angling was not popular at this place.

The variation in the relative sizes of the Indus valley fish hooks evidently shows that hooks of different sizes were employed for catching different kinds of fishes. While the Mohenjodaro specimens vary between the lengths of 2-9" and 1-04", the Chanhudaro hooks vary between the lengths of 1-87" and 0-43". The difference in the relative sizes of the hooks indicate that fishing was probably confined to tanks and small streams at Chanhudaro whereas at Mohenjodaro all fishing was done in the Indus.

It cannot be denied that although the majority of the Indus valley sites are situated on the bank of navigable rivers, yet artefacts connected with boats and navigation from among the archaeological finds have not been discovered. Circular stones of various sizes (1/2" to 4′ in diameter) with central hole have been found at Harappa and Mohenjodaro. Such stones are conspicuously absent from the sites at Chanhudaro. The large ringstone with heavy weights might have been used as anchors for boats.

Fishing nets have been identified from paintings on a pot-shred found at Harappa. It shows a fisherman carrying two nets hanging from a pole across his shoulder. Some fish and turtles are lying close to his nets. The fisherman stands on a cross- hatched band possibly a river as identified by Vats (1940).

Net-sinkers discovered from various sites may be classified into two types, namely (i) hollowed or annular and (ii) grooved. While type I has been found from Mohenjodaro, type II from Mohenjodaro and Chanhudaro both. Reports from Harappa do not contain any reference to net-sinkers.

II

Fisheries occupies an important place in Indian tradition and mythology. The *Ṛgveda-Saṃhitā* throws light on the mode of hunting of fish and the food and drink of people. The Vedic Aryans appear to be meat eaters rather than fish eaters. However, *matsya* as fish is mentioned in the *Ṛgveda*. *Muksija* is also found in one passage of the *Ṛgveda* which clearly means a "net" for catching fish or animals.

In *Atharvaveda* and *Śatapatha Brāhmaṇa*, reference to fisheries has been made by narrating a legend in which a fish saved Manu from deluge. The Vedas, the Saṃhitās, Brāhmaṇas, the Āraṇyakas and Upaniṣads contain several references of fisheries.

Fish names appear in these texts. However, these names may refer to an individual species or to a genus as a whole. For example, the terms like *Purikaya*, *Jasu Matsya* and *Sakula* may refer to some genera or species of fishes.

In the post-vedic period, fish was caught by nets, hooks hands or by damming streams and baiting with poison as evident from the various names mentioned in *Yajurveda*.

Sāyaṇa (*Taittirīya Brāhmaṇa*) says that *Dhaivara* is one who takes fish by netting a tank ; *Dāsa* and *Sauskala* do so by means of fish hooks (Baḍisa) ; *Kaivarta* and *Mainala* by means of net (*Jāla*) ; *Margara* by means of hands; *Anda* by putting pegs in dams and *Parṇaka* by putting a poisoned leaf in the water.

After the Vedic period, separate treatises were written which framed rules concerning social laws, rituals and domestic ceremonies. These were respectively

called *Dharma-Sūtras*, *Śrauta-Sūtras* and *Gṛhya-Sūtras*. The *Smṛtis* deal with the same subjects but in a more elaborate way. It gives more prominence to social laws. Hence, it is also known as the Dharma-Śāstras.

We find only casual references to fish in the *Sūtras* and the *Smṛtis*. Nevertheless, they reveal to a considerable extent the part played by fish in man's affairs in those early days in India.

References to specific types of fish have been made in different contexts particularly either in connection with the 'Śrāddhas' (i.e. ceremonies wherein food is offered to the manes but is actually consumed by Brahmana priests) or with certain forbidden foods.

The *Mahābhārata* is full of references to a large variety of animals many of which are common to *Rāmāyaṇa* and Vedic literatures. Vedavyās, the writer of *Mahābhārata* is a son of Matsyagandhā and sage Parāśara. Arjuna of *Mahābhārata* married Draupadī by shooting the target of a fish eye. His daughter-in- law Uttarā, wife of Abhimanyu, is said to have a fish origin. Sage Sauvarī was attracted to a family life by seeing a fish moving happily with its off-springs.

The names of three fishes have been frequently referred to in the *Ramayana*. These are :

(i) *Cakratuṇḍa* or *Garra mullya* (Sykes)

(ii) *Nalamīna* or *Mastacembelus armatus* (Lecepede)

(iii) *Rohita* or *Labeo fimbriatus* (Cuvier & Valenciennes)

In the north-western recessional of *Rāmāyana*, instead of *Cakratunda* and *Nalamina*, *Sakula* and *Pathina* are mentioned. *Sakula* of the *Rāmayāṇa* or *Saula* of Bengal is the snake-headed fish, *Ophicephalus striatus* (Bloch). *Pathina* of the *Rāmāyana* or Boal of Bengal is a cat-fish known as *Wallago attu* (Bloch).

In *Rāmāyaṇa* Lakṣmana is advised to use an arrow (shot from a bow) for catching fish (iii. 73) in the crystal clear water of the Pampa lake and in the marshy areas around, full of reed. The second method of catching fish is referred to by means of a baited hook or angle.

At the lake Pampa, Lakṣmaṇa is advised to have the scales cleared and the fishes roasted in an iron pan over the rife (iii. 73. 15). In Araṇyakāṇḍa (76.24), Rāma and Lakṣmaṇa are advised to cook rice and fish with salt and red pepper on reaching an *āśrama* on the west bank of the Pampa lake. Thus, roasting fish on fire and the use of salt and red pepper appear to be very ancient traditional practice in India.

There has been a lot of references regarding animal sacrifices in the Vedas but unfortunately, the Zoological knowledge of the Vedic period has not yet been fully elucidated. The *Chāndogya Upaniṣad* has classified animals on the basis of their ovum or seed (*bīja*) into three groups.

(1) Born of eggs (*Aṇḍaja*)

(2) Born of fully developed or viviparous (*Jīvaja*)

(3) Born as plant-like organism (*Udvījja*)

Further, the animals have been classified into eight classes on the basis of their feeding habits and habitats. The animals living in water logged areas, marshy lands

or even grazing on river bank were called *Anūpa*. The class *Anūpa* appears to represent an important class as it also included the group "Matsya" which according to Rao (1956) represented both fresh water and sea water fishes.

III

Caraka gives classification of animals based on therapeutic values of flesh. The dietic value of flesh of an animal was conceived to depend mainly on its habitat and mode of life it leads. Dietary animals were accordingly divided into eight classes including fishes in the class *Anūpa*.

The *Suśruta Saṃhitā's* classification of animals is based on their origins. The animals were divided into four groups :

(I) *Jarāyuja* or (viviparous) - e.g. mammals

(II) *Aṇḍaja* or (oviparous) - e.g. fishes, birds, reptiles

(III) *Svedaja* (born out of heat and moisture) - e.g. ants, worms etc.

(IV) *Udbhijja* (born out of vegetation) - e.g. fire-flies, tadpoles etc.

The second system of classification is based on habit and habitats of the animals. These are :

(1) *Jāṅgala* (animals that live in jungle, dry or hilly lands) (2) *Anūpa*-aquatic or amphibious animals (animals living in marshy or water logged areas).

The class *Anūpa* is further divided into five sub-classes. The fishes were given place in the sub-class, '*Matsya*' which included both fresh water and sea water fishes. About more than twelve inland or fresh water fishes have been described in this text.

The animals were classified according to whether they were born sexually or asexually. Umasvati in his work *Tattvārthādhigama* evolved another method by which animals were classified into four categories based on the number of senses possessed and used by them.

The fishes were assigned the fourth category in which animals with five well developed senses of touch, taste, smell, sight and hearings were placed.

The fourth category was further subdivided according to the mode of production. Fishes were placed in the sub-group "*Aṇḍaja*".

Suśruta not only enumerated a number of fish species that have food value but also gave the relative medicinal properties possessed by different fishes. Hora (1955) stated that fresh water fishes are more nutritious than the marine fishes. According to him, the non-protein nitrogenous components such as trimethylamine oxide and urea which are present in marine fishes, putrefy more readily and thereby reduce their palatability and sale value. The fresh water fishes on the other hand, do not contain these components and can stay fresh for a relatively long period. In ancient days when refrigeration was not known, the relatively high merit of fresh water fish as an item of diet in India could thus, be readily understood.

Kauṭilya *Arthaśāstra* is the earliest known dated work of the ancient Hindus. The life of the people and their agriculture including fisheries science during the Buddhist period and in the Magadhan empire are well documented in it. Then we

have Jātaka stories which tell us about the previous incarnations of Lord Buddha, the sculptures of the railings and gateways of the stupas of Bharhut and Sanci. The Nanda dynasty was over-thrown by Candragupta Maurya in 325 B.C. whose chief adviser was Kauṭilya, also known as Cāṇakya or Viṣṇugupta. He was the author of the Arthaśāstra.

Hora (1948) consulted Shamasastry's English translation of the Kauṭilya Arthaśāstra (2nd edition, Mysore, 1923) and made the following references from this translation.

(1) *Role of fisheries during shortage of food* : Book IV, Chapter III, deals with remedies against national calamities under famines. The passage is significant for it shows that in the ancient days the invading armies carried a supply of dried fish with them. As such, the art of processing fish must have been known to those people.

(2) *Fishery management* :- In Book II, Chapter I, it is stated (p. 51) that 'the king shall exercise his right of ownership (svamyam) with regard to fishing, ferrying and trading in vegetables (heritapanya), in reservoirs or lakes (setuṣu)'. The reservoirs referred to in this passage appear to be irrigation tanks. These reservoirs or tanks in those early days were used for fish culture enterprise. Book II deals with the 'Regulation of toll-dues'. As contained in Chapter XXII (p. 135), imported commodities were charged one-fifth of their value as toll. In case of perishable articles such as flowers, fruits, vegetables (śāka), roots (mula), seeds, dried fish and dried meat, the toll was one-sixth of the value of the articles. The noteworthy point is that dried fish must have been a regular trade commodity in those days and therefore, the methods of processing fish must have been known to the people.

(3) *Rendering fishes poisonous* : Kauṭilya deals with secret means to injure an enemy and suggests a mixture and treatment for rendering fishes poisonous (Book XIX, Chapter I, pp. 478, 479).

Fish and fisheries have been extensively referred in *Jātaka* literature comprising 547 stories (Hora and Saraswati, 1955). According to them, the varieties of fish mentioned in the Jātakas and their identifications are as follows :-

(i) *Ānanda-maccha* (=Rhineodon typus, the Whale shark), Jataka 32.

(ii) *Kanamahamaccha* (= Catla catla), Jātaka 38

(iii) *Mahamukhamaccha* (= Wallago attu), Jātaka 288.

(iv) *Rohita* (=Labeo rohita), Jātaka 454

(v) *Velamaccha* (=Carcharias gangeticus), Jātaka 402.

(vi) *Ksura-nasika* (= Pristis cuspidatus), Jātaka 463.

(vii) *Suvannavanna-maccha* (= Puntius sophore), Jātaka 491.

(viii) *Kumbhila* (=Tetraodon), Jātaka 529.

(ix) *Pavusa* (= Callichrous pabda), Jātaka 545 & 451.

(x) *Valaja* (= Mastacombelus armatus).

(xi) *Muñja-rohita* (=Labeo rohita), Jātaka 451 & 545.

(xii) *Pṛthuloma* (=Scaly fish), Jātaka 545.

Inscriptions of Aśoka who succeeded Bindusāra on the Mauryan throne in 246 B.C. have been found engraved on rocks, separate stone blocks and stone pillars. These have been designated as *dhamnalipis*, translated as "edicts of the law of piety (morality)". Aśoka's pillar edict V, deals with regulations for the protection of many varieties of animals. Five varieties of fish or fish like animals are included in this Edict. These five species of fish in this pillar edict were discussed and identified by Hora (1950) as :

Anathikamachhe (sharks), *Vedaveyake* (eel fish), *Gaṅgāpupuṭake* (fresh water porpoise, fish-like creature), *Samkujamacche* (skate or ray), *Kaphatasayake* (globe fish)

Indian sculpture is largely an expression of the religious beliefs of the people. Fish are, however, found in reliefs illustrating the *Jātaka* folk-tales, either in connection with the theme of a story or to indicate some points in its artistic treatment.

The Jātaka sculptures clearly indicate that Rohu and Kātla were the most popular fresh water fishes of the Northern India during the second century B.C. The representation of fishes in the Bharhut sculptures are sufficiently accurate to permit identification.

The *Saṅgama* literature is an important source of information about the economy and social life of the people of South India. A few species of fish are referred to in the *Saṅgama* literature. Coins of the Pandyan kingdom are stated to bear the fish symbol as the Chola and Chera coins bear other animals.

During Gupta dynasty Kalidasa's *Abhigyān Śakuntalam* deserves particular mention. We find that Duśyanta and Śakuntalā were reunited through a lost ring obtained from a fish.

IV

From the 7th century A.D. to 11th century A.D., the fisheries declined. We get only one reference of fish production in Rajpur Kingdom of North India. The text of '*Matsyavinoda*' in '*Mānasollāsa*' written by king Someśvara in 1127 A.D. is the first known treatise on the art of angling in India. He classified fishes according to their habitat and size. He dealt with those fishes that are common in the sport of angling.

The tackle for angling is dealt with by king Someśvara under the heading - line, hook and rod. He suggested that the rod, line, hook and bait have to be adjusted according to the nature of the water, size of fish and their feeding habits.

Someśvara's advice on fishing is of interest:

(1) *Ground Bait* : He considers regular ground baiting as a necessary condition preceding actual fishing.

(2) *Tackle* : The examination of the tackle to be used for fishing is Someśvara's next instruction. He advises that one should determine the length and thickness of the cord and rod by taking into consideration the depth of the water and the size of the fish. He further says that the size of the hook should be consistent with the length of the cord.

(3) *A Quill Float* : A float in the form of peacock-feather should be tied in the middle of the cord to watch its movement when the fish touches the bait.

(4) *Bait* : Flour or meat, whatever is liked by a particular fish desired for sport, should be put on the hook as a bait.

(5) *Striking a fish* : As soon as the movement of the feather is noticed, the angler should strike with a sharp pull.

(6) *Playing as fish* : When a fish gets entangled on the fishing hook, it becomes very vigorous. One should haul it up, as soon as it gets exhausted, taking care that the cord does not give way.

Thus it seems probable that Someśvara's '*Matsyavinoda*' probably contains the accumulative knowledge about fishes and fisheries of the later half of the 10th century, the whole of the 11th century and nearly three decades of the 12th century. In any case, the knowledge recorded is remarkably accurate and instructive and could be used in pond cultural practices to which considerable attention is now being paid in India.

The justification for the present compilation of the hitherto known but scattered facts is that enmasse, they may furnish a better prospective of fisheries science in ancient India.

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Town Planning, Building And Building Materials

H.C. BHARADWAJ

I. Town Planning

Town is the symbol of the social organization. Its planning mainly depends on the ingenuity of a particular culture to systematise the township in accordance with the topography and ecology of the land, needs of the society and the governing agency.

In India, there is evidence of the conscious planning of cities from the days of its earliest civilization viz. Indus civilization which prospered in a large part of Indian subcontinent, with an area of about half a million square miles during 2300-1750 B.C.

There is ample evidence to show that Indus Valley town planning was not inspired by any contemporary civilization including that of Sumerians. It was an indigenous development that the genius of Indus culture can be rightly proud of and which did not appear in Athens even 2000 years later.

After the demise of Indus civilization there is hardly any evidence of city life for about a thousand years and it is only around 600 B.C that there is a second phase of town planning. The study reveals that this second phase was neither earlier survival nor revival and the least an import. It is believed to be *sui generis* (Ghosh, 1973).

While there is no literary evidence of the town planning during Indus culture, there are a large number of literary passages and accounts which bear testimony to the second phase of town planning which continued staggeringly till it merged with the present through its chequered history.

For both first and the second phase of town planning, archaeological evidence is more reliable. The literary accounts give an exaggerated picture and the dates of these works are not always reliable. Nevertheless, the latter do help in supplementing the archaeological skeleton.

Indus Civilization

Indus Civilization had a vast expanse with its northern boundary at Rupar in Haryana, and the southern at Bhagatrav (Gujarat) eastern and western boundaries being Alamgirpur in U.P. and Sutkagendor(Makran) respectively, occupying an area equal to 1.25 million sq km; larger than the present Pakistan.

A large number of cities of this civilization have been excavated which reveal uniformity in the lay-out of the cities. Mention may be made of Mohenjo-daro, Harappa, Lothal, Kalibangan etc. The examination of the lay-out of these cities reveals that they consciously planned their cities and kept in mind the following factors :

1. The topography and the ecology of the area, (being riverine civilization) they selected long river fronts.
2. They chose rectangular area, kept proper orientation and followed the cardinal points.
3. The need for defence and prevention from floods made them to improvise the system of fortification and ramparts.
4. The division of the city according to the dictates of the society, building important quarters on the citadel and ordinary houses at the ground level.
5. They followed grid-iron system of laying out the streets, cutting each other at right angles.
6. High level of sanitation system and underground drainage.
7. Adequate means and regular system of water supply, through wells and tanks.

City planning takes effect largely through some governing agency and requires understanding of the ecology (in this case, the riverine ecology) and the means to exploit it. This would require adequate organization to execute large scale works of elaborate fortification and layout of the city and construction requiring experienced architect, masons, carpenters, with facilities of surveying, analysis and designing.

Excavations at Mohenjo-daro and Lothal etc have brought to light geometrical and surveying instruments for precise measurements and fixing cardinal points.

A brief mention may be made of some of the salient features of Harappa, Mohenjo-daro, Kalibangan and Lothal towns of the Indus civilization.

All the towns, big or small show regular orientation. The towns of Harappa, Mohenjo-daro and Kalibangan depict two distinct features, namely, on the west there is a distinct citadel mound which is artificially built on a high podium by use of mud bricks. From the center of the citadel branch out long axis running north-south and to the east. The citadel outstands the lower city which houses the main residential area. Either both the citadel and the lower city or at least the citadel were surrounded by massive fortification wall.

Harappa: The town extended over a circuit of 6 km on the left bank of Ravi. The site is now in Punjab province of Pakistan. It has been identified with Rgvedic

Hari-Yupiya by Wheeler. There is a lower town and a citadel in the shape of a parallelogram (Vats, 1941).

Mohenjo-daro: Situated on the right bank of the Indus in Larkana district (Sindh: Pakistan). The city has a parallelogram shaped citadel 50 feet high and the lower town. The city had 12 blocks extending over 1.5 km. Granary and Great Bath are situated on the citadel. Great Bath measures 17×7×2.5m. It has the distinction of remarkable water proofing device using bitumen. Bricks are set on edge in gypsum, below the bricks was a damp-proof course of bitumen held by further wall of bricks. Sanitation methods are mentioned separately. (Marshall, 1931).

Kalibangan (Dt. Ganganagar; Rajasthan): Both the citadel (240 m N-S×120m E-W) and the lower town (240 m E- W×360 m N-S) are parallelogram in shape and are surrounded separately by a massive defence wall which is 3.5 to 9 meter thick made of mud bricks of 40×20×10 cm size in its earlier phase and 30×15×7.5 cm in its later phase. The fortification wall is mud plastered and is reinforced with rectangular salients and bastions.

There are four arterial thoroughfares in north-south direction and three or four in east side. Street corners are provided with fender posts to avoid damage from vehicular traffic. Roads are unmetalled except in the last phase. House drains discharged themselves into soakage jars, buried under the street floor. Streets were laid in perfect alignment.

Widest streets run across the lower city from north-south. Roads are twice as broad as the street and the latter are twice as broad as the lanes. The city shows regard to the cardinal points.

The citadel town had important buildings, civic, religious, administrative and also the granaries. General population lived in lower town (Lal, 1978).

Lothal (Dt. Ahmedabad, Gujrat): Situated at the head of gulf of Cambay, north-west of the junction of Sabarmati and Bhagavo rivers. Being a port town it had a somewhat different lay-out. The city is rectangular. The longer side, 300 meter had a north- south orientation and the shorter side 225 meter had east-west expanse. There was a massive mud-brick defence wall surrounding the city as a protection against the flood.

Port town is situated on a low ground by the side of a tributary of Sabarmati river. On the eastern side of the township is a dock-yard (detailed separately). The citadel, 7 meter high, constructed of mud brick, situated on the south eastern flank of the city, houses all the important establishments of the city - the acropolis. It measured 119×127m with longer axis north- south. All important buildings: public and private houses, and the warehouse, were built in of 12 cubical blocks with air ducts and passages running in between. Mention may be made of a series of rooms with a brick paved bath having remarkable system of underground drainage with silting chambers and cess pools -these might have been the ruler's residence.

Streets were four to six meter wide and narrow lanes two to three feet broad. Main street ran north to south (Rao, 1973).

Sanitary and drainage system

It can be safely inferred that the Indus civilisation had some central authority which asserted for the development and maintenance of the roads. Care was often given to paving of streets, and drainage. Regard for traffic and hygiene were advanced.

The Indus Civilization had exemplary right angled plans. It is clear that the authorities exercised their control to prevent the rise of tortuous alley characteristic of later cities.

The houses had a pronounced batter or slope and never encroached on the streets as is found at present. All houses had latrines and bath rooms disposing their waste into street drains. Houses had rubbish chutes, at the foot of which were some bins at street level. The rubbish bins stood at convenient places in the streets. The waste water entered the drains from tightly closed brick lined pits which had outlets to the drains about three quarters of the way up. These may be taken as forerunners of our septic tanks and grit chambers.

Each street or lane had one or two drainage channels about 18"-24", below street level and an area of 9"-12" or 18"-24" of the drainage channel was either covered with stone slabs or was roofed.

The streets usually ran from east to west or from south to north. Some important streets were 15 to 33 feet wide. Average roads were 9ft to 12ft wide. Most were unpaved, though some having burnt bricks pavements were found with joints grouted with gypsum mortar or bitumen.

Literary Evidence

Literature fails to give a realistic picture of town planning. Such descriptions are exaggerated and conventional, yet repetitive mention of high defense walls, deep ditches and moats, wide streets, large portals, busy markets, flowering trees, gardens and ponds needs to be critically examined.

Aryans were not city dwellers but were known as destroyers of cities and were called *Purāndara.* But building activity must have been there and growth of 'pattanas', the port town. Rgvedic architects were pre-eminently carpenters and built houses with wood, bamboo, thatch etc.

Panini mentions two divisions of town: *Udicyagrāma* and *prācyagrāma* viz. Kauśāmbi, Taksaśilā, etc. according to him most important parts of the town were; moat (*parikhā*), rampart (*prākāra*) and gate (*dvār*); the latter were named after the cities towards which they opened.

Buddhist texts and Jataka stories mention *paṭṭana* (port-town) *nigamas* (market town), *dūrga* (forts) etc which show urban development which needed some systematisation and thus planning. *Milindā pānho* mentions the architect (Veddahi/Vardhaki) searching:

1. Faultless pleasant spot free from rocks, hills, gullies and not open to danger of attack.
2. The city is then laid out in regular measured quarters, with excavated moats and ramparts on all sides. With high towers and strong gate houses, with

cross roads, street corners, market places, public squares, with clean and even roads, lined by shops, parks, lakes and gardens etc.(Milinda-panho 1928)

The Jain canonical text *Aupapatika-Sūtra* enumerates the important parts of the township as, 1. moat (*parikhā*) broad at the top and cut deep down, 2. solidly built rampart bent like a bow and provided with buttresses, bastions (*aṭṭālayas*), with gates (*toraṇa*) towers (*gopura*) and high roads (*Rājamārga*) etc. It also provided with junctions of 3, 4 or 6 roads.

Pānini mentions moat (*Parikhā*) gate (*dvār*) and rampart (*Prākāra*) as the most important parts of the city.

In *Arthaśāstra* a *grāma* was 1 or 2 Krośas in length. In the center of 800 villages was a *Sthānīya* (district town), of 400 villages, a *droṇamukha* (big town) of 200 villages a *Khārvaṭika* (town) and amongst 10 villages was a *saṅgrahana* (small township).

The *Sthānīya* could be circular, oblong or square in plan. The city was divided by three streets, running eastwards and three towards north. Each extremity of the street was to have a gate thus making up 12 gates in all. The main roads had the width of 4 daṇḍas or 24 feet. To avoid congestion roads were allotted for different purpose. Arthaśāstra mentions five kind of roads: *Rājapatha*, *Devapatha*, *Mahāpatha*, *Rathya* and *Caryā*.

The city had fixed position for various classes of people. The palace was in the center facing north or east. Temples of Gods also occupied central position. Surrounding the place were the houses of Brāhmins. The Ksatriyas, the Vaiśyas and Sudras occupied north, east and south parts respectively.

The corners were set apart for the guilds. Intermediate portion was marked for market, the houses of the royal priests and officers and so on.

Kautilya describes many kinds of roads classifying them according to their use and destination. Each road had a specified width varying from 4 feet for pedestrians and 32 feet to 64 feet for royal roads and trade routes. Roads were made with a convex surface (like the back of the tortoise) and were provided with drains on either side, water flowed down through these drains.

Further there are detailed passages on town planning in *Bṛhat Saṃhitā*, Śilpaśāstra compositions: like *Mayamata*, *Mānasāra*, *Yuktikalpataru*, *Samarāṅgana-sūtradhāra* and *Nītisāra* of Śukrācārya. Mention may be made at *Mānasara* on town planning.

According to *Mānasāra* a work of c. 11th century A.D. smallest town unit was 100×200×4 cubits and largest was 7200×14,000×4 cubits. *Mānasāra* suggests that the cities should be built near the sea, a river or a mountain and should have facilities for trade and commerce and should be laid either from east to west or from North to South, according to the site.

Mānasāra divides town into eight classes: (*Rājadhāni*, *Nagar*, *Pura*, *Nagarī*, *Kheta*, *Khārvaṭa*, *Kubjaka* and *Paṭṭana*) and mentions the plan of a city (nagar). It had high, perhaps concentric walls about it in which were watch towers, massive gates, strong doors, protected chiefly by wide bridge moat, latter filled with

crocodiles and armed with paling, guarded the walls. The city was laid in several squares. The streets were lighted with torches. The principles of Indian Town Planning have some striking similarity to those of early European cities and it is interesting to compare *Mānasāra* with the work of Vitruvius (a work of c. 25 B.C.).

The important subjects considered by *Manasara* and *Mayamata* are:

1. *Bhū-parīksā* - (examination the land)
2. *Bhumi-saṃgraha* (selection of the town site)
3. *Dikpariccheda* (determination of the cardinal points)
4. *Padavinyāsa* (surveying and mapping the area and marking into squares).
5. *Balikarma vidhāna* (sacrificial offering).
6. *Grāma Vinyāsa, Nagara Vinyāsa* (planning of villages and towns).
7. *Bhūmi Vinyāsa* (construction of storeyed buildings).
8. *Gopura Vidhāna* (construction of gate-ways).
9. *Rajaveśma Vidhāna* (construction of palaces).
10. *Maṇḍapa Vidhāna* (construction of temples)

Śukranītisāra depicts city planning in an elaborate manner headed by *Gṛhadhyāpati* - the minister of town planning and in order of hierarchy stood Sthāpati (master architect),*Sūtragrāhik* (Surveyor) and *Takṣaka* and *Vardhaki*. In this text the central place is given to the Sabhā and areas are allocated to others depending upon their status and occupational classes. Wealth and cast were the main criterion. Regarding cardinal points of the lay-out of the city, he follows *Arthaśāstra* tradition viz. city buildings should face either the north or the east. It lays great importance on the selection of a site for the capital of the kingdom. The place should abound in natural wealth of flora and fauna, rich source of water and be navigable up to the sea and be even plain and picturesque and, not, far from the hills.

Second Civilization

Around 6th century B.C emerges the second civilization in India and we find the coming up of the capital cities of the sixteen *Mahājanapadas* (great kingdoms) like those of Kauśāmbi, Rājgir, Campā, Vaiśāli, Kāśī, Śrāvasti, Ahicchatra, Hastināpura, Mathura, Ujjain, Taxila etc. This civilization brings with it the fortified cities, kiln burnt bricks, highways which promoted long distance trade and communication and introduction of coinage and meaningful use of iron.

During the period of 6th century B.C. to early centuries of Christian era we get planned cities, with fortification wall, gates, bastions and towers (made of mud, unbaked bricks, baked bricks, wood and stone) some cities have moats, well laid and planned roads, streets and properly aligned houses with cardinal points in mind, reasonable systems of drainage, sanitary provisions, and system of water supply.

Fortifications have been brought to light by archaeological excavations at Eran, Kausambi, Rajghat (Kāśī), Ujjain, Old Rajgir, New Rajgir, Campā, Śrāvasti, Ahicchatra, Vaiśāli, Śiśupālgarh, Pāṭaliputra (here wooden defensive wall has been partly traced) and Taxila etc. The fortification walls have a large circuit: 6.5 km at Kauśāmbi, 5 km at New Rajgir (old Rajgir has a circuit of 40 km stone fortification

but its date is not confirmed, it ought to be of the days of Bimbisāra). These fortification are not strictly planned. However the fortification of Śiśupālgarh, Sirkap and Taxila are well planned. At Rajgir and Mathura there were inner protection enclosures. Śiśupālgarh has later fortification. Most mud fortifications have partial or fully baked brick revetment.

Moats: At Sanghol there is evidence of three moats, first outside the rampart and the other two inside. But this is of late 5th century A.D.

The moat at Ujjain 8.1 meter deep is lined by a brick wall. It belongs to Pd I around 6th century B.C. Moat has been reported from Vijayapuri (Nagarjunakonda) from historical levels.

Kauśāmbi (Dt. Allahabad, U.P) Earliest evidence of town planning in early historical period comes from Kauśāmbi. The excavations in the area near Aśokan pillar revealed a planned city. The road excavated in the area controlled the plan of this city. Every house had access to this road either directly or through the lanes or by-lanes. The road joined one of the principal thoroughfares of the city connecting the Aśokan pillar area with various parts of the city and eastern gateway. Aśokan pillar stood at the junction of this road and principal thoroughfares. This plan continued from 4th century B.C to A.D. 400. The lay-out of the excavated city reveals the existence of a number of cross walls provided with doors which could be closed for protection and security.

Alignment of houses: Houses were aligned with roads and lanes and generally maintained correct orientation with cardinal points.

Sanitation System: The city shows well developed hygiene. The drainage devices include: ring wells, soakage jars, terr-cotta pipes, open brick drains, covered brick drains and brick tanks. These provisions served well for draining off water from houses and disposal of sewage.

Śiśupālgarh (Orissa): It is the best planned city of the 3rd century B.C. Its defensive wall was constructed in the first quarter of 2nd century B.C. There is evidence of large scale use of laterite blocks of massive size for gateways and monoliths and was reinforced by the brick 'boxes' filled with earth in next century. From the regular disposition of the eight gates: two on each of the 4 sides of the wall. The excavated remains reveal grid-pattern lay out. (Details of the fort city are given separately in another chapter)

Sirkap: It is new city of Taxila, founded by Indo-Greeks. It was extended and fortified by masonry wall and fully planned with spinal streets running from north gate throughout the length of the city, with smaller lanes meeting it at right angles. Houses are well defined. Sirkap is not a representative city of indigenous planning.

Vijayapuri: Excavations at Nagarjunakonda have laid bare the remains of the ancient city of Vijayapuri of historical period which displayed a well thought out plan with a citadel and residential area. The citadel was fortified complex with a moat. A tank with an elaborate drainage system has been brought to light. Structures show linear pattern in their arrangements with roads. Amongst the excavated secular remains is an amphitheatre with gallery on all sides and a bathing ghat.

Arikamedu: It is located on the eastern bank of a lagoon formed by Ariyankuppam river, about 3 km south of Pondicherry. Excavations have revealed a planned port city of Indo-Roman period datable to 1st-2nd century A.D.

Most important architectural remain is the 150 ft. long, oblong brick structures of a ware house, near the water level. Mention may be made of two tanks each with an adjacent room, extensively paved. It shows elaborate series of conduits and drains and pavements of large stones. Such an elaborate drainage system, some of the drains being constructed by means of corbelled wall, floored and roofed with horizontal bricks is quite unique in early cities of ancient India. The city continued to be occupied till 11-12th century A.D.

Delhi : Excavations at Purana Qila (Thapar, 1985) in Delhi has brought to light the remains of the old city of Indraprastha associated with Pāṇḍavas. The excavations have revealed continuous occupation from Pre-Mauryan days - through Mauryan, Sunga-Śaka, Kusana, Gupta, Post Gupta and Rajput periods, finally giving way to Delhi Sultanate and Mughal period. Details of town plans and structural activity is being worked out to throw light specially on Post -Gupta and Rajput period.

Warangal (Andhra Pradesh): This is a unique circular city dating back to 12th century, when it was founded by Gaṇapatideva a prominent Kākaṭīya ruler. The city is defined by three concentric circles of fortifications. The outer two are of earthen rampart, protected by a moat. Four arched stone gateways are positioned at cardinal points. The inner circle is entirely limit of stone. The four gateways in these walls have large double-bent entrances; door frames and balustrades are typical features of the Kākaṭīya period. The four roads of the city converge on a ruined temple in the middle. Four free- standing portals leading into the temple still stand.

Medieval fortifications have been reported from Lal Kot (Delhi) from Deogiri (Dt. Aurangabad) and Dabhoi (Dt. Vadodara) These fortification were elaborate and built as fortresses and cities with moats and gateways.

For forming some idea of an ancient Hindu city one may mention Vijayanagar which remains the best preserved medieval Hindu capital town in India. An archaeological investigation of its urban lay-out and the chief monuments so far exposed, reveal sufficient information regarding the plan of the city as well as the form of individual elements viz. walls, roads, gateways, hydraulic works, residential quarters, palaces, civic buildings temples, shrines. It is situated on the bank of Tungabhadra river, regularly fortified having spectacular setting with granite landscape on the north, dominated by a gorge through which Tungabhadra river flows, to the south and west there to an extensive plain, on the South bank are the sacred shrines (around the village of Hampi). There is an irrigated valley to the south through which ancient canals still run. This separates the fortified urban core which is enclosed by a ring of massive fortification defining an elliptical zone about 4 km along its axis. Within the urban core there is an abundant evidence of habitation, temples, gateways, tanks and wells. At the south western end of the urban core, a cluster of enclosures encircled by high granite walls constitutes the royal center of the capital containing : palaces, temples, columned halls, treasurary, watch towers, tanks and wells etc. Gateways are located along the roads leading into the urban core.

II. Building and Building Materials

The existence of great variety of useful stones and wood and employment of bricks, mortars and plasters have greatly contributed to the magnificent achievements of India in the field of architectural engineering.

Stone and Rock Architecture

Choice of stone for large structures depends upon its hardness, toughness, porosity, strength and its internal structure (property on which depends the ease or difficulty in quarrying and dressing).

Harappan: Though man came in contact with stone in pre-historic times its earliest systematic use in India came around Harappan times when massive rough stone walls of unhewn stone were raised. Sometimes these are ten to fifteen feet high. These were built across the course of seasonal streams apparently as a crude effort intended to conserve an intermittently abundant flood water.

Exclusive use of stone and rubble was made for raising fortification at Surkotda, an Harappan site in Kutch, dating to 2100-1600 B.C.

Use of certain pieces of worked stone at Harappan sites suggest as if these were segments of pillars, but it is not clear whether these were employed structurally. However hammer dressed lime stone slabs were occasionally found covering brick drains. Probably such blocks were quarried with copper - bronze chisels and hammers of stone. Transport of such blocks would have required exacting team work.

Iron age megaliths (datable to c. 1000 B.C.) have a large expanse from the extreme south, throughout most part of peninsula. This culture worked with various rocks in which granite and gneiss predominate. In the Malabar coastal laterites, small rocks cut chambers are found. Some times these chambers are approached by an entrance from above and covered with a cap stone. Some of these chambers have vaulted roofs.

Some megalithic graves show stone alignment, comprising carefully oriented rows of standing stones, set in a square or diagonal plan. The standing stones are generally 1.5 to 2.4 meter in height, but occasionally examples of over 6 meter height are recorded. Small alignments have been reported with as few as three rows of three stones, four rows of four stones, five rows of five stones etc. But sometimes large diagonal alignments with many hundreds of standing stones are reported from Gulbarga district. These monuments are mainly distributed in Central Deccan and in the districts South Hyderabad.

Rajgir : On the top of the Vaibhara hill at Rajgir, there is a remarkable stone structure locally known as *maśān* (watch tower) called *Jarāsandha-kī-Baithak*, a monument noticed by Huien-Tsang. It is usually identified as the residence of Pippala and Mahākṣapa of Buddhist tradition: this monument is the earliest structure of stone in India. These are watch towers - providing shelter for the guards. It is in the form of a large rectangular platform 85 ft.×81 ft at the base and 22 to 28 feet high.

It is built of large unhewn blocks of stone set in the rock without any mortar and contains near the base several small irregularly shaped cells on all sides. Its walls, like those of rectangular bastions of the outer city walls of old Rajgir have a slight batter.

Śiśupālgarh: There has been massive use of laterite blocks and pillars at Śiśupalgarh. Laterite blocks of an average size 6×2×1 feet have been recovered from Western Gateway (SP IV). Further towards the centre of the fort, there is group of sixteen pillars of laterite, some still intact. The average height of the pillars above the ground is 14-15 feet.

Maurya Architecture

Mauryas made a remarkable contribution to stone architecture. They introduced stone masonry on a wide scale. Magasthenes states that Maurya palace at Pataliputra was as splendid as that in the capital of Iran. Fragments of stone pillars and stumps indicate the existence of eighty-pillared hall, discovered at Kumrahar on the out-skirts of modern city of Patna. This attests to the technical skill attained by the Maurya craftsmen in polishing the stone pillars, which have maintained their polish even to-day.

Some new methods and techniques were developed to carry the huge blocks of stone from quarries, to polish and embellish them and for placing them erect. These stone pillars and columns are monolithic (made of a single piece of sand stone. Only their capitals which contain beautiful sculptures in the form of lions, elephants, horses and bulls are joined with pillars on the top. All this seems to be a great engineering feat.

These polished pillars of sand stone were set up throughout the country, this points out to the development of transport technology. Mention may be made of some of the Aśokan pillars:

1. Most celebrated of the pillars is the one of Sarnath (near Varanasi). This lion capital now serves as emblem of modern India.
2. Lauṟiya - Nandangarh pillar of Orissa.
3. Bull capital of Rāmpurvā pillar in U.P.
4. Pillars of Allahabad (U.P.) and Sanchi Pillar (M.P.) with lion capital.

Maurya artisans also started the practice of carving out caves from rocks for monks (*see under* 'Rock-Architecture')

Stone and Rock-cut Architecture : Earth is made up of layers of rocks, one above the other. Indian sub-continent is endowed with various landforms, varying in height and slope and may be classified into there major types : mountains, plateaus and plains, and is provided with rock shelters, caves and stone quarries.

Natural Caves and Rock-Shelters : Early man in India inhabited the natural rock shelters and caves from lower palaeolithic time onwards. Mention may be made of the rock shelters of Bhimbetka and Adamgarh in Madhya Pradesh, those of Gudium (a few miles from Madras), Chenchu group of rock shelters in Andhra Pradesh and the rock-shelters near Mirzapur in U.P. etc. These early people were acquainted with stone quarrying and tool making.

From Mauryan times onwards there is development of a specific Indian architecture known as rock-cut architecture. It is also known as monolithic (single upright block of stone), that is to say that shrines were excavated in solid rock, either by hollowing out the necessary sanctuaries (chambers): the caves, the *caityas* and *vihāras* or by cutting away the exterior rock so as to leave an entire temple of solid rock.

Of the former, some of the earliest examples of rock-cut architecture are found in the granite outcrops of twin Barabar and Nagarjuni hills of Bihar where seven cave temples date from 3rd century B.C. There are Mauryan period inscriptions which indicate that these caves served as retreats for Jain monks. The interiors are remarkable for their mirror-like polished surface as seen at Sudama and Lomaś Ṛṣi Cave.

The beginning of monumental architecture in the Deccan is also of rock-cut sanctuaries and monasteries belonging to Śātavāhana period (2nd century B.C. - 2nd century A.D.). These monuments are excavated into basalt out-crop of western Deccan at numerous Buddhist sites including those of Ajanta, Bedsa, Bhaja, Junnar, Karli, Pitalakhora. During later phase (Śātavāhana- Kṣatrapa transition, first-second century A.D. the *caitya* halls of Kanhere and Nasik show more evolved arched motifs and decorative reliefs on the facades. Ajanta was provided with superb series of *caitaya* halls under the Vākāṭaka (5th - 6th century A.D). Under the patronage of the Kalacuri and Early Cālukyas (5th - 7th century A.D.) rock-cut caves and temples developed further as seen at Elephanta, Jageshwar, Ellora, Aihole, Badami etc.

There is another resurgence under the Rāṣṭrakuta rulers in rock- cut architecture, most important being that of Ellora. In south, during Pallava period (7th century A.D.) rock-cut caves and temples were executed into granite as witnessed at Mamallapuram, Mandagapallu and Tiruchirappalli.

In western India, under Kṣatrapa rulers of Junagarh (3rd/4th century. A.D.) monasteries for Buddhist and Jains were cut into the rock at Girnar. There is a group of 16 Jain sanctuaries on a rocky cliff at a height of 2100 feet, datable to Solanki period.

In central India a series of 20 cave temples assigned to Gupta period are reported from Udaigiri near Vidisa in Madhya Pradesh. These are excavated into sandstone ridge.

Earlier 35 cave temples were excavated into sandstone out-crops of Udayagiri and Khandagiri near Bhubaneshwar (Orissa). These were excavated under the patronage of Chedi Kings of first century B.C.

Some later examples of rock-cut architecture imitated free standing buildings. At Mamallapuram in Southern India, granite boulders were cut into monolithic copies of temples during 7th century A.D. The most impressive monolithic monument is the Kailas temple at Ellora, also datable to this period. Here, a great ditch was excavated into a cliff exposing a solid mass of rock, this was then hewn into a free standing monolithic temple, complete in all of its architectural details; from the mouldings of the basement to the dome like roof of the tower.

Monolithic solid rock architecture is also known from north India. One such representation is the fifteen towered temple datable to 9-10th century A.D. at Masrur near Kangra (Himachal Pradesh).

Rock-Cut Cave temples : Beginning with Maurya period rock-cut caves and temples my be taken as an achievement of Maurya Period. They scooped into hard and refractory quartzose-gneiss outcrops at Sitamarhi near Gaya district the caves of the Barabar and Nagarjuni hills. The technology developed further during Gupta period. The rock-cut caves included scooping out of the laterite, sandstone, granite, gneiss, charnockite and bed rock. Pallavas alone chose the hardest rocks like granite and gneiss.

Techniques of Scooping : Some of the unfinished caves give an idea and clue of scooping, chiselling and polishing practices adopted by the ancients.

First of all, the outline of the facade was incised by driving a tunnel into the rock, beneath the place where the ceiling would be. For this, small and closely spaced cubical holes were drilled along the selected line for breaking. Dry wooden cubes were forced into these holes and then wetted, their swelling caused the stone to crack and break. Bronze and iron chisels and mallets were the main cutting tools.

Considering the present day traditional craftsman it is likely that during Gupta period high quality steel chisels having a width between 1 to 2 cm, with two functional ends one pointed and another with broad cutting edge were used.

Sometimes, the rock-face was divided into 2 to 3 feet square blocks and deep grooves were cut between these blocks, which were then hewn off. This process was repeated until required depth was achieved. The concussions of the heavy hammer helped to remove sizeable pieces of the rock.

For reaching appropriate height metallic footholds were provided. The work of scooping, and chiselling off the projecting squares was done by vertical, lateral and centripetal strokes.

Carving, Dressing, Pecking, Grinding and Polishing : For carving out monolithic columns, brackets, doorways and windows, position of the facade pillars, cornices, beams and doorjams etc. the portions requiring carving were first marked and then carved out. These were finished by more careful and light strokes of chisel by experienced and trained artisans. After blocking, scooping and carving out different architectural members, the dressing of surfaces were made even by parallel straight chiselling as can be noticed in Lomas Rsi cave. The ridges produced by the above mentioned chiselling were removed. In this process of thinning called as *pecking* one chisel mark overlaps the other and prepares flat surface ready for grinding and polishing. *Grinding* is done (after even surface is produced by pecking) with the help of coarse grained stone, coarse sand and wetting the surface throughout the process. In this process a vigorous rubbing of the surface was carried out, removing all ridges, pitts, moles and chisel marks. Pillars and all other members were also given this treatment before polishing. For *polishing* some shining agent was supposed to be added during polishing, but this is not supported by factual evidence. The shine is the result of extensive burnishing with fine stone and fine grained sand. It brings out polished surface which in some cases glistens rather than shinning. The final shining surface also depends upon the quality of the stone.

Bricks

Bricks both unbaked and baked are standard building material since Pre-historic times. Their use has been attested from Pre- Harappan levels. Bricks are made of clay which is easily available in plenty in alluvial lands and was economical for use. It could be moulded in desired shapes, dried in the sun and used in unbaked form. Sun dried bricks were baked for use in structure to withstand weathering and resist wear-and-tear to last longer.

Unbaked mud bricks or adobe was used extensively in Pre- Harappan and Harappan times and upto historic period. Even to day unbaked bricks are used in undeveloped rural areas specially in arid and semi-arid regions.

Nature of clay: The soil used for fabrication of bricks consists mainly of clay along with natural impurities of the soil as quartz, mica, feldspar, calcite, kaolinite, depending upon the basic material from which the soil is formed. Main criterion for the mud to be useful for moulding bricks is its plasticity. Pure clay is very plastic and natural impurities affect its plasticity. The nature of the minerals, shape and size of the grains, presence of soluble salts and organic material influence the suitability of the soil for bricks. Plasticity can be increased by adding selected clay and can be decreased by adding quartz, sand, slag, organic material like husk of rice, or chopped straw. The composition of the brick varies according to the region.

In *Yajurveda-Saṃhitā* and *Śatapatha Brāhmaṇa* hair of goat, very fine sand, pounded rock and iron filings are mentioned as degressant material. These materials help in holding the non-plastic ingredients of the clay together. Use of *Ukhya-bhasmą* is mentioned as an additive to mud for making bricks in *Baudhāyana Śulba Sūtra*. Most of the bricks are rectangular, yet bricks in various shapes and types: square, wedge shaped, L Shaped, decorated and inscribed have been used according to their specified use.

Wedge shaped bricks are found for steening wells, and are reported from Harappan period onwards. These are also used for construction of circular structures in early historic period. e.g.. at Lauriya Nandangarh, Kaundinyapura for stupas.

Square bricks have been reported from a large number of sites (vide infra).

Round and cubical bricks are also known

L-Shaped bricks - the Ksatrapas, Guptas and later rulers used decorative pieces by moulding. This is attested from Bhitargaon, Nibiakhera, Sirpur, Nalanda, Vikramsila etc. Such bricks were used in eastern India till medieval times.

Light weight bricks - these were made specifically where heavy bricks could not be used. These were made by adding to the clay such material which will be partially burnt out releasing carbon dioxide. For this the clay was mixed with limestone, organic matter like saw dust etc. At the Ramappa temple at Palampet (Andhra Pradesh) the use of light bricks is noted. The *Śikhara* there is made of such bricks. These bricks have low density and can even float in-water.

Bricks used in Śyena-citi (Altars) - Bricks of typical shapes and sizes are noted from Kausambi and Jagatgram. These are also inscribed.

Size of bricks: On the basis of measurement of bricks from various Harappan sites and structures the range of the size in cm is: 50 to 25 (length) × 25 to 12.5 (width) × 12.5 to 6.35 (thickness); keeping the general ratio of 4:2:1. The most common size is 28 × 14 × 7cm. A few examples may be necessary - earliest use of bricks (unbaked and baked) is attested for the first time from Pre-Harappan levels at Kalibangan (Dt. Ganganagar, Rajasthan)

Kalibangan: 30 × 20 × 10 cm (laid in English Bond) and the ratio of length: breadth: thickness is 3:2:1. (Pre-Harappan level). A large number of Harappan sites have been excavated and there is a great variety of structures and hence despite the standardization there is bound to be different sizes and shapes. Kalibangan Harappan levels reveal two sizes of bricks 40 × 20 ×10 cm in the earlier phase and 30 × 15 × 7.5 cm in later structural phase, both have the same ratio e.g. 4:2:1. (Harappan level).

Banawali (Dt.Hissar, Haryana): Pre-Harappan levels reveal unbaked bricks and following sizes in the ratio of 3:2:1 (as that at Kalibangan) are recorded: 30 × 20 × 10 cm, 36 × 24 × 12 cm, 39 × 26 × 13 cm an aberrant size square in nature is also reported e.g. 24 × 24 × 12 cm.

Mitathal (Dt. Haryana): Here also Pd I the size of the brick is 30 × 20 × 10 cm and in PD IIA the size is either 40 × 20 × 10 cm or 36 × 18 × 9 cm. (4:2:1).

Surkotda (Dt Kutch, Gujrat) Some structures show 40 × 20 × 10 cm size (4:2:1).

Daimabad (Dt Ahmadnagar, Maharashtra): Here too in Period II (Late Harappan) the size is 32 × 16 × 8 cm 28 × 14 × 7 cm (4:2:1).

Post-Harappan Chalcolithic context: At Gilund (Ahar culture) mud bricks of the size 40 × 22 × 7 cm and 33 × 13 × 10 cm and baked bricks of 35 × 15 × 12 cm have been reported. These look to have no resemblance with Harappan size.

O.C.P. and P.G.W. Cultures: Some old bricks and brick fragments have no doubt been reported from O.C.P. culture for example from Lal Qila, Saipai, Bhagwanapura and Hastinapura. Their number is limited, there are no structural remains nor any intact brick.

From Kausambi large sized bricks have been reported in very large number, from 9 feet thick rampart dated to c. 1000 B.C. their size is 48 × 33 × 7 cm.

At Hastinapura some bricks have been reported from P.G.W. level but these are fragmentary and only their thickness is known to be 5.6 cm.

N.B.P.W. Culture: There are regular brick structures during this phase datable to 600 B.C. to 200 B.C. and have been reported from a large number of sites but these do not fall in any fixed dimension. A few examples are given below:

Hastinapura itself has three sizes 45 × 25 × 7 cm. 30 × 23 × 6.5 cm and 37 × 23 × 6.5 cm.

Bricks from Mathura measure 40 × 24 × 5 cm and those from Kausambi show a range with 48 to 35 L × 30 to 18 B × 7.6 to 5.6 Th. Rajghat (ancient Varanasi) again has range of bricks 50 to 48 L × 31-29 B × 7 to 6 cm Th. Most common size taking all the N.B.P. sites is 45 × 24 × 7 cm.

Mathura (Kankali Tila tank) has three sizes 40 × 25 × 5 cm. 30 × 26 × 4 cm and 30 × 17 × 5 cm; Hastinapura bricks of this period measure 37 × 22 × 6.5 cm and 28 × 28 × 10 cm (the latter are square). Eran bricks measure 43 × 23 × 7.5 Sringverpura bricks range 41.5 to 44 × 27 to 28.5 × 5.5 to 7 cm.

Gupta Period: Brick size during the Gupta period also shows a wide variation. Large bricks like 61 × 31 × 9 cm and small bricks 19 × 19 × 16 (square) are found. A few examples giving range of length × breadth × thickness in cm will illustrate the point:

1. *Sārnāth* : 41.91 to 22.86 × 29.21 to 17.78 × 13.97 to 5.08 cm Square 22.86 × 22.86 × 5.08
2. *Rājghat* : Unbaked 48:26 × 22.86 × 9.27, baked 40 × 24.76 × 9.72
3. *Kuśīnagar* : 39.37 to 20.32 × 24.13 to 12.7 × 6.98 to 4.44
4. *Śrāvastī* : 60.96 to 24.13 × 30.48 to 20.32 × 8.89 to 5.08
5. *Bhita* : 4.72 × 15.24 × 7.62
6. *Kumrahār* : 45.72 to 30.48 × 33.02 to 22.86 × 17.78 to 3.98
7. *Vaiśālī* : 41.26 to 13.97 × 27.94 to 13.97 × 6.35 to 5.08
8. *Bodhagayā* : 18.58 to 11.43 × 18.58 to 11.43 × 15.54 to 11.43 (Square bricks)
9. *Bhītargaon* : 45.72 to 33.02 × 26.67 to 22.67 × 7.62 to 5.08
10. *Ahicchatra* : 45.72 to 25.4 × 26.67 to 21.59 × 8.4 to 5.08
11. *Candraketugarh* : 33.02 to 30.48 × 22.86 × 5.04 to 4.44
12. *Ratnagiri* : 45.72 × 22.86 × 7.62
13. *Eran* (Pd III) 38.10 × 27.94 × 10.16
14. *Devnimori* : 48.26 to 40.64 × 33.02 to 15.24 × 24.76 to 6.35
15. *Taxila* : 45.72 to 25.40 × 35.56 to 17.78 × 6.35 to 5.08
16. *Kaveripattanam* : 41.91 × 24.13 × 10.16
17. *Paharpur* (Bangladesh) Round bricks of 16.0 cm, 13, 10.5 cm diameter and cubical bricks 7.62 × 7.62 × 7.62
18. *Bharauch* : 7th century A.D. 40.64 to 30.48 × 27.94 to 20.32 × 7.62
19. *Thaneshwar* (Harsha's time) 35.56 × 21.59 × 6.35
20. *Burogoan* (Dt. Jhansi A.D. 10th century) 35.0 × 23.76 × 6.35 445; 0×29.84×6.35.

The above description of the size of the bricks from N.B.P.W. phase to Gupta period and onwards brings out the fact that bricks though made in moulds do not show any standardization as prevalent during Harappan period. This is mainly due to the fact that no scale was prevalent (none has been reported from any site after the Harappans). The measurements were taken from human body, length of the brick was based on *hasta* (forearm e.g. cubit), breadth on *vitasti* (stretched hand or

span) and the thickness was based on four *aṅgulas* (fingers). As this varied from person to person, the variation in the size of bricks can be explained as done by Lal (1983).

Mortars and Plasters

Amongst the building materials mortars and plasters are important ingredients, mortar may be defined as a material used for building or cementing the building materials e.g. bricks or stones. Plaster is the material used for coating walls etc. Some times the same material may be used as a mortar as well as for plaster. In ancient period mud was almost exclusively used as mortar and plaster. Though gypsum and lime plaster/mortar have been used during antiquity. The earliest use of lime and gypsum comes from Indus civilization.

At Harappa, gypsum cement of light grey colour was used in certain buildings. It consists of variable mixture of sand (20 to 40%), gypsum (45 to 75%) and lime (2 to 25%). Lime mortar with sizeable percentage of magnesium is also used in Indus Civilization. It contains calcium carbonate (26 to 57%), magnesium carbonate (4 to 11%) and sand clay (34 to 61%). The high percentage of sand and clay in lime plaster suggests that it was prepared by burning *Kaṅkar* (calcarious nodules). The use of lime was restricted to drains and floors. (*See Table 1*).

From the analysis of various samples of mortars and plasters from Mohenjo-daro, it may be concluded that gypsum mortar/plaster was quite common. Lime plaster was generally mixed with gypsum, but lime plaster free from gypsum has also been reported both from Harappa and Mohenjo-daro. The use of lime and gypsum mortar was confined to drains or floors where mud mortar was of no use. Gypsum and lime mortar are stronger and resistant to water.

Lime mortars have been used at Kausambi. These date from 600 B.C. to A.D. 100. But it may be emphasized that by and large only mud mortar and plaster were used. The results of the chemical analysis (*Tables 2 and 3*) show that the content of sand in the mortar, was slightly higher than that in plasters. The average ratio of sand : lime $Ca(OH)_2$ is about 1:1, whereas in the case of mortars the average is 2:1. For mortars, probably 2 parts of sand were mixed with one part of slaked lime.

Lime Plaster from Karwan (Dt. Vadodara, Gujrat) from pre- Gupta levels : From the analysis (*Table 4*) it is clear that two types of plaster was used. Samples 1 to 4 represent the upper coat of the plaster and 5 to 8 represent lower rough plaster. The former has higher content of lime as compared to the latter. Fine layer was laid and burnished to make it smooth and elegant.

Lime Plaster from Bhitari (Dt. Gazipur. U.P) (Gupta Period) : shows low grade lime plaster (*Table 5*) was used at the brick temple of Gupta period. It has sand and lime ratio of 6:1. The red colour of the plaster/mortar is due to the use of ferruginous *kaṅkar* for preparation of lime.

Lime Plaster from excavations at Nalanda (7th-10th century A.D) (*Table 6*) shows 3 parts of lime (calcium carbonate) and 2 parts of sand. Some of the monasteries are thickly plastered. Jars with dried up mortar and a cell used as a cistern in monastery No 11 are indicative of the preparation of concrete.

Lime Plaster from Lingaraj temple at Bhubhaneshwar (Orissa - 10th century A.D) (*Table 7*) shows that lime:silica ratio was 3:1.

Cola and Nayaka Plasters show two types of plasters used : rough and fine, it has a ratio of 1:1 of lime : sand in rough plaster, and 9:1 in case of fine plaster. Nayaka rough plaster 1:3 lime : sand ratio, while fine plaster has 4:1 ratio.

Lumps of finely made lime in the shape of balls have been found mostly from late Jorwe levels at Inamgaon (datable to first millenium B.C.). Sometimes these have been carefully stored in pots. In one house of late Jorwe phase a largė number of lime balls were found. This indicates some people were engaged in the manufacture of lime. Significantly a heap of shell, was noticed near the house, but no kiln.

Lime kiln for manufacturing Lime : Kilns were rudely constructed of stone blocks and usually located in a cavity. In charging the kiln large pieces of limestones were formed into a dome like arch with large open joints and kiln was filled with fragments of lime stones. The larger pieces of lime stone were placed above the arch and kiln was topped with fragments of small size. Kiln was charged with alternate layer of lime stone and fuel (wood). Bright heat was maintained for three or four days at a temperature of about 95°C, lime stone, kankar modules, sea shells are converted into quick lime (CaO) and CO_2 gas is evolved. Before using it is slaked by mixing it with mater and slaked lime is mixed with sand or bajari for masonry work.

In addition to the above, mention may be made of use of clay, lime, gravel and hydraulic lime from post-chalcolithic levels at Navasa.

At Taxila, lime is used extensively during Parthian levels. Though at Bhir mound there is no evidence of the use of lime plaster. At Sirkap lime was used for finishing both internal and external surfaces. Floors at Julian (Takile) were covered with *bajari*-lime concrete.

At Arikamedu lime mortar is reported from historical period. Use of lime is also attested from Hullas Khera (Dt. Lucknow) from Kuṣān-Gupta levels and from Banagarh (Dt. Dinajpur) where use of lime and *Surkhi* is known from Gupta and Pala levels. At Purana Quila lime plastered gutter connected with house drains is reported from levels datable to 8th-9th century A.D.

Wood

Wood and the vegetable world supplied the first building materials and wood was amongst the first constructional material for buildings. Post holes supporting wooden posts or bamboos have been identified from prehistoric settlements right from neolithic times. Sanskrit (*Mārkaṇḍeya Purāṇa*) and Pali literature (*Jātakas*) *Arthaśāstra* and *Rāmāyaṇa* show that buildings were generally made of wood. That wooden architecture prevailed in India for a long time is attested by the fact that when other material was used the buildings were made after their wooden models. The pillars, the arch, the door and the mouldings of the early caves all disclose their indebtedness to buildings made of wood. From the use of bamboos came the

Table 1–Percentage Composition of Gypsum and Lime Plasters and Mortars from Harappa and Mohenjodaro

Chemical Constituents	Mortar from Mohenjodaro	Mortar from Mohenjodaro	Mortar from Harappa	Plaster from Mohenjodaro	Mortar/Plaster from Mohenjodaro	Mortar/Plaster from Mohenjodaro	Mortar from earthen ware Mohenjodaro	Mortar from drain & cesspool Mohenjodaro	Mortar from floor at Harappa	Lump of Mortar from Harappa (Floor)	Mortar from Harappa (Floor)	Mortar from Concrete floor at Harappa
Ca SO_4 $2H_2O$ (Gypsum)	72.3	74.12	56.9	43.75	63.25	56.7	-	-	-	-	-	-
Ca CO_3 (Calcium carbonate)	-	2.50	0.94	13.78	1.64	25.0	69.58	39.96	35.02	56.51	26.5	37.63
Mg CO_3 (Magnesium carbonate)	-	-	-	-	-	-	-	8.82	10.62	4.81	8.46	2.18
Sand & Clay	-	20.41	42.16	38.04	31.52	-	21.71	47.48	51.39	34.35	61.60	59.29
Alkaline Salts	27.7	1.18	-	2.47	2.56	18.3	5.44	-	-	-	-	-
Moisture (Water)	-	1.79	-	1.96	1.01	-	3.27	3.74	2.97	4.33	3.44	0.90
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 2 – Percentage Composition of Lime Plasters and Mortars from Kausambi (based on Satya Prakash and N.S.Rawat:1965) (Dt. Allahabad)

Sample No.	CaO	Insoluble sand, etc	MgO	$CO_2 + H_2O$	Moisture	P_2O_5	SO_2	$Fe_2O_3 + Al_2O_3$	Cl, Alkali	Total
1	31.12	33.43	2.01	24.08	1.42	0.51	0.30	7.13	-	100.00
2	28.41	41.40	1.38	20.16	1.63	0.72	0.39	4.65 tr		98.74
3	28.08	39.13	1.21	21.09	2.37	0.71	0.41	7.00	0.30	100.30
4	29.00	36.37	0.63	21.12	2.88	0.60	0.34	8.93	-	+ 99.87
5	25.06	44.49	0.92	18.29	3.44	0.68	0.29	6.60	-	+ 99.77
6	15.12	65.39	1.98	9.20	2.73	0.48	0.31	4.49 tr		+ 99.70
7	18.53	57.37	1.80	13.00	1.48	1.12	0.51	6.19	0.62	100.62
8	27.51	38.09	1.30	19.29	3.10	0.99	0.56	9.67 tr	100.51	

Table 3 – Ratio of sand and slaked lime based on Table-2 in Plasters and Mortars from Kausambi

Sample No	1	2	3	4	5	6	7	8
Sand	33.43	41.40	39.13	36.37	44.49	65.37	57.37	38.09
Slaked lime $Ca(OH)_2$	41.11	37.53	37.09	38.30	33.10	24.48	24.48	36.34
Ratio of Sand and $Ca(OH)_2$	3:4	1:1	1:1	1:1	4:3	3:1	2:1	1:1

Table 4 – Percentage Composition of fine lime plaster Samples (1 to 4) and rough lime plaster (5 to 8) From Karwan (Dt. Vadodra, Gujarat)

Sample	1	2	3	4	5	6	7	8
Ca CO_3	94.12	94.28	94.46	94.26	69.98	74.26	71.88	68.34
Sand	5.88	5.72	5.54	5.74	30.02	25.74	28.12	31.66
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 5 – Percentage Composition of Bhitari (Dt. Gazipur. U.P.) Plaster

Sample	Si O_2	Ca O	MgO	Fe_2O_3	Al_2O_3	Alkali	Total
1	73.40	13.65	1.85	6.45	0.65	1.75	97.45
2	74.20	13.42	1.76	4.50	2.60	1.46	97.94

Table 6 – Percentage Composition of Plaster samples from Nalanda

Sample No.	CaO	$CO_2 + H_2O$	Clay and Sand	MgO	Fe_2O_3 + Al_2O_3	NaCl	H_2O	SO_3	Total
1	33.95	25.84	27.5	1.13	7.84	-	2.24	0.27	98.79
2	34.78	30.30	23.41	1.30	5.54	2.40	2.16	0.40	100.29

Table 7 – Percentage of Plaster sample from Lingaraj temple Bhubaneshwar (Orissa) 10th century A.D.

CaO	CO_2 + H_2O	Clay + Sand	mgO	Fe_2O_3	Cl	H_2O	SO_3	Total	Lime Sand ratio
37.30	33.31	19.26	3.12	5.62	0.23	0.68	0.78	100.30	3:1

Table - 8 – Percentage Composition of Cola and Nayak Plasters

Description	Ca O	CO_2	SiO_2	Fe_2O_3 + Al_2O_3	MgO	SO_3	Moisture	Alkalies	Total
Chola rough plaster	27.88	18.05	49.97	1.89	0.51	0.26	0.38	1.05	99.99
Chola fine plaster	65.59	25.13	7.02	1.06	0.37	0.58	0.23	-	99.98
Nayak rough plaster	18.56	9.38	63.39	3.69	0.33	0.17	3.14	1.34	100.00
Nayak fine plaster	55.58	23.67	13.76	1.59	1.02	0.59	3.77	-	99.98

curvilinear type of roof which was later reproduced in cut timber and subsequently in stone and from which were evolved the *caitya* arches.

For protection of wood from white ant and other corrosive effects the wooden posts were set in jars of earthern ware. The *Ṛgveda* refers to the dwelling places but the characteristics of the buildings are not clear. From the reference to *Tvasta*, it is clear that master architect was a carpenter and wood was the main material used along with others. *Takṣaka* in later architecture means a mason whose duty was to give fine shape to the stone, wood or the brick (*Mayamatam*, ch. V. 20).

Though stone architecture was followed by the Buddhists, the Hindus continued to build their houses, *Prāsādas* & *Devālayas* in bricks and wood.That is why no Hindu temple is known before Gupta period. The brick and wooden temples have perished for ever.

The main structure of Mathura temple of Vāsudeva, the Heliodoros temple of Vāsudeva at Besnagar have not been preserved.

Aryans lived in wooden and brick houses and being strict followers of Vāstuvidyā hesitated to depart from that tradition. Stone structures were made by non-Aryans.

Wood has been used as constructional material from neolithic times. Post holes in early neolithic settlements confirm this. As wood is perishable material only a fragment of what was used has come to us. In Harappan period it was used in conjunction with bricks masonry, for door frames, door leaves and as wooden beams for roofing purposes. Use of timber has also been attested for making embankments or wooden walls.

Variety of wood has been identified from archeological sites. Special mention may be made of Acacia (*babūl*), Adina cardifolia (*haldu*), Albizzia (*kokko*), Anogeissus (*baklī*), Casearia (*cilla*), Cedrus deodara (*deodār*) dalbergia spp. (*śiśam*), Dendrocalamus sp (Bamboo), Mangifera indica (Mango) Pinus roxburgii (*cira*), Shorea robusta (*sāl*) and Tectonia grandis (*teak*).

Important sites from where wood samples have been identified are: Lothal (Harappan), Atranjikhera (O.C.P) Śiśupālgarh (early historic),Jagatgram (early historic 'aśavamedha' site),Patliputra (Patna) early historic period.

Identified specimens from various sites are mentioned below in alphabetical order :

1. Acacia Sp. (*babūl*): Lothal and Rangpur (Harappan) Maski and Prakāsh (Chalcolithic) and Śiśupālgarh (early historic).
2. Acacia nilotica (L) Del (*babūl*): Atrainjikhera (O.C.P)
3. Adina cardifolia (*haldu*): Lothal (Harappan)
4. Albizzia sp. (*kokko. sirisa*): Lothal
5. Angoissus sp.(*baklī*: From all levels of excavations of Prakash.
6. Bassia latifolia (Roxb).(*mahuā*): From Kirari, yupa (early historic)
7. Boswellia serrata (Roxb) *salai*: From Śiśupālgarh (early historic).
8. Casearia Sp. (*cilla*): From Śiśupalgarh (early historic).

9. Cedrus deodara (*deodār*): From Harappa, Mohenjo-daro Atranjikhera (N.B.P.W)
10. Cupressus torulosa (*devidiar*): From Atranjikhera (N.B.P.W.).
11. Dalbergia sp. (rosewood) *śīśam*: From Prakash (early historic).
12. Dalbergia latifolia (black *śīśam*): From Harappa, Prakash (chalcolithic).
13. Dalbergia Sissoo (Sissoo): (*śīśam*)/ From Monhenjo-daro, Atranjikhera (O.C.W.), Hastinapur (Late Historic).
14. Dandrocalamus Sp. (Male Bamboo): From Prakash (Chalcolithic, N.B.P.W.).
15. Diospyros sp. (Ebony): From Arikamedu (early historic).
16. Heritier Sp. (*sundari*): From Arikamedu (early historic).
17. Holarrhena antidysentrica (*kurchi*, *karci*): From Prakash (chalcolithic) Śiśupālgarh (early historic) Hastinapur (late historic).
18. Madhuca latifolia syn *mahua*: From *Kirari*, *Yypa* (early historic).
19. Mangifera indica (mango): From Jagatgram (early historic site of *Aśavamedha*)
20. Mimusops (*mūlsarī*): Arikamedu (early historic).
21. Pinus roxburgii (*cīr*): Atranjikhera (P.G.W.) Pinus sp. (Pine): Harappa.
22. Shorea robusta (*sāl*): Atranjikhera O.C.P., Jagatgram (early Historic), Patliputra.
23. Soymida febrifuga (*Rohan*) From Lothal (Harappa), Śiśupalgarh (early historic).
24. Tamarix Sp. (*Jhāu*) From Rangpur, Atranjikhera N.B.P.
25. Tectona grandis (teak): From Lothal (Harappa) Prakash (Chalcolithic) Atranjikhera (Black and Red Ware).
26. Terminalia tomentosa: From Prakash (Chalcolithic) Atranjikhera, N.B.P., Jagatgram Aśvamedha site (early historic).
27. Zizyphus sp. (ber): Harappa.
28. Ulmus lancifolia (*elm*): Harappa.

Wood is of perishable nature. However fragmentary evidence of timber is available:

Harappan : Universal flat roofs with evidence of sockets indicate that square cut beams with spans of as much as 4 meter were used for roofing at most of the Harappan sites in India and Pakistan. Timber was also used for semi-structural frame or lacing for brick work.

Taxila: Use of timber for the upper floors and roofs as well as for varandahs, doors and smaller fittings.

Bairat (Dt. Jaipur): Octagonal columns of wood, 26 in number have been identified on the basis of charred stumps.

Śiśupālgarh: The wood has been used for gates.

Large Scale use of timber at Patliputra

The excavations at Kumrahar, Bulandibagh and Kankarbagh have exposed extensive remains of massive timber pallisade of ancient city of Patliputra, which is believed to have been founded a year before Buddha's death and which became capital of Magadhan empire shortly thereafter. Magasthenes also mentions this wooden palli-sade. According to him the pallisade had numerous gates and watch towers surrounded by a-deep moat.

It might have been constructed in the time of Nandas who built first an all-India empire in historic period with Pataliputra as the capital, rather than by Candra Gupta Maurya as might be inferred from the statement of Magasthenes.

Archaeological excavations in 1926-27 resulted in the discovery of east-west wooden structure running for a distance of about 137 meters. It is a wall made of heavy wooden sleepers placed vertically in a double row with similar sleepers joining them horizontally at the bottom. In 1935 a similar structure was found at Gosainkhanda 800 meter east of Bulandibagh but here the wooden structure had a reverse design viz. the vertical sleepers were capped by horizontal ones.

Kumrahar excavations during 1951-55 have not brought to light any wooden boundary walls, or railings or wooden floor of the hall. The hall was probably destroyed by fire during Sunga period. Hall may not be a part of the palace of Aśoka as mentioned by Fa-Hien and was destroyed long before Fa-Hien's visit to India.

The temples of Brahmaur, Catrarhi, Manali and Camba (datable to 8-9th century) all in Himachal Pradesh, have carved wooden doorways, columns, beams, and ceilings, still surviving. There are temples wih wooden architecture in U.P. also, mention may be made of temples at Sarahan and Jageshwar. Cedar wood has been used in Himachal.

Though India's early wooden architecture has not survived, techniques derived from this tradition influenced later rock-cut and masonary monuments. Among the timber, bamboo and thatch elements that were preserved in later architecture are circular or part circular plans, curved doorways and window openings and domed and barrel-vaulted roof forms.

The earlist rock-cut Buddhist and Jain sancturies had timber- like ceilings with cross-beams and rafters: actual teak ribs were even inserted into the stone vaults. Clearly, these artificial caves were intended as copies of timber structure. Stone posts and rails that surrounded stupas also imitated timber originals, even to the details of jointing, so too did the stone gateways with carved architraves known as 'toran'. Masonary details of temples were often wooden in origin: projecting blocks on basements and cornices were derived from the ends of timber beams, doorways had jambs and lintels of timber designs. Towers with curved profiles and roofs with barrel-vaulted or dome-like tops were also wooden in origin as were the curved cornices but like roofs of brick temples in Bengal in eastern India, or the sloping stone roofs of temples in coastal southern India. Some completely wooden structures have survived the corrosive effects of India's climate. In the Himalayan valleys and in Kerala, temples have carved timber doorways, columns and beams, angled wooden brackets etc.

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Fortification And Forts

M.S MATE

Concept of Fortification

The erection of a physical barrier between oneself and an anticipated enemy is the basic concept of fortification. The nature of the barrier changes with reference to the thing to be protected and the danger to it perceived by its protectors. To cite an example, the object of protection could be a temporary camp and the danger apprehended might be of wild animals; or, it could be a whole city and the danger might be posed by an army equipped with artillery. In the case of the former, a train of carriages chained to each other and small screens of tough branches or bamboos in between, would be enough whereas in the case of the latter strong stone walls of considerable height and thickness would be needed. However, the basic concept is the same - a physical barrier. The fortification is thus static, purely defensive in purpose and is in the nature of a well thought-out reaction to a given set of circumstances. Since these might change, and the nature and size of the objects to be defended might change, the nature of fortification would undergo a corresponding change.

Fortification in Literature

Before the extensive application of archaeological methods to the ancient past, students had to depend on literary sources for information. Apart from the Epics and the *Purāṇas* which give descriptions of cities like Lanka, Hastinapur or Dwarka and which might be dismissed as outcomes of poetic imagination, a body of scientific literature exists, consisting of the *Arthaśāstra* of Kauṭilya, the *Smṛti* of Manu and several treatises on *Vāstu Vidya*. All these treat *Dūrga vidyā* as a separate branch of architecture and engineering. The *Arthasasastra* explains the varieties of forts like land forts (*Bhū-dūrgas*), forest forts (*Vana-dūrgas*) and sea forts (*Jala dūrgas*) and so on. Such features as battlements, (*Kapiśirṣas*) turrets or bastions, gates and moats find a mention in these texts. The Epics mention various projectiles, however, it is difficult to ascertain both their existence and their nature. Interestingly none of the battles in these Epics are described as having been fought

around fortifications; all battles were fought in the open ground, armies clashing head on. Moreover, these works do not describe in detail the principles, mainly with reference to defensive strategies, employed in the construction of the forts. Their main utility is that they testify to a long experience in the art and craft of fortification; for texts like the *Arthaśāstra* are an embodiment of communal experience spread over generations, may be centuries.

Fortification in Art

Sculptural representations dated to the first and second centuries B.C. from places like Barhuṭ, Amravati and Sanchi depict walled towns. The walls are surmounted by triangular battlements and have massive gates or gate-houses. These gate- houses were the precursors of laterday '*Gopuras*' found in temples of South India - with two tall pylon-like structures on either side and a '*śālā*' type of structure surmounting and joining them. Soldiers manning these walls carry swords, javelins and bows and arrows. No projectiles other than arrows are in evidence. The size of the gate can be inferred from the fact that in almost every depiction an elephant with riders on its back is emerging from it.

All these, the poetic as well as plastic representations, were treated with some reservation by scholars and gradually greater reliance came to be placed on material remains, that is, archaeological data uncovered through excavations.

The earliest traces of fortifications found on the Indian subcontinent belong to the Harappans, dated to between 2500 B.C. to 1700 B.C. (Mate, 1970, pp. 75-84). Some sites like Kot Diji perhaps have slightly earlier defences whereas in Gujarat they spill over the fifteenth century B.C. The area covered by this civilization is vast, comprising as it does present day Pakistan, parts of India, Punjab, Rajasthan and northern Gujarat. Within this area, more than a hundred villages or stations of the Harappans, at least some seven townships and a number of outposts have been located, surveyed and excavated to a greater or lesser extent. If as the Allchins (1968) suggested, Sandhanawala, Judeirjodaro and Darbar Kot (all in Pakistaṇ), turn out to be major townships, the number of towns would be ten. Of these at least nine have yielded evidence of town-walls. There however seem to be two categories in these townships, some are enclosed in while others have only their citadels so protected.

Desalpur, Lothal and Kalibangan are examples of the former while Harappa, Mohenjodaro are of the latter. In the case of the latter sites there are two different entities the smaller one (citadel) well defended, whereas the bigger (township) inhabited by the general public is left undefended (*Fig. 1*).

Some important sites are noted below.

Harappa was the first place where large-scale fortifications were noticed. The citadel at this place is a rough parallelogram measuring 450m x 210m. It is between nine to twelve meters higher than the surrounding plains. The defences rest on pre-Harappans deposits which show signs of heavy flooding. These inroads of water were first filled up with mud-bricks and the whole was then raised to a higher level with baked bricks. This served as an anti-flood bund, spreading protectively beyond the outer foot of a great defensive wall 14m wide at the base and tapering

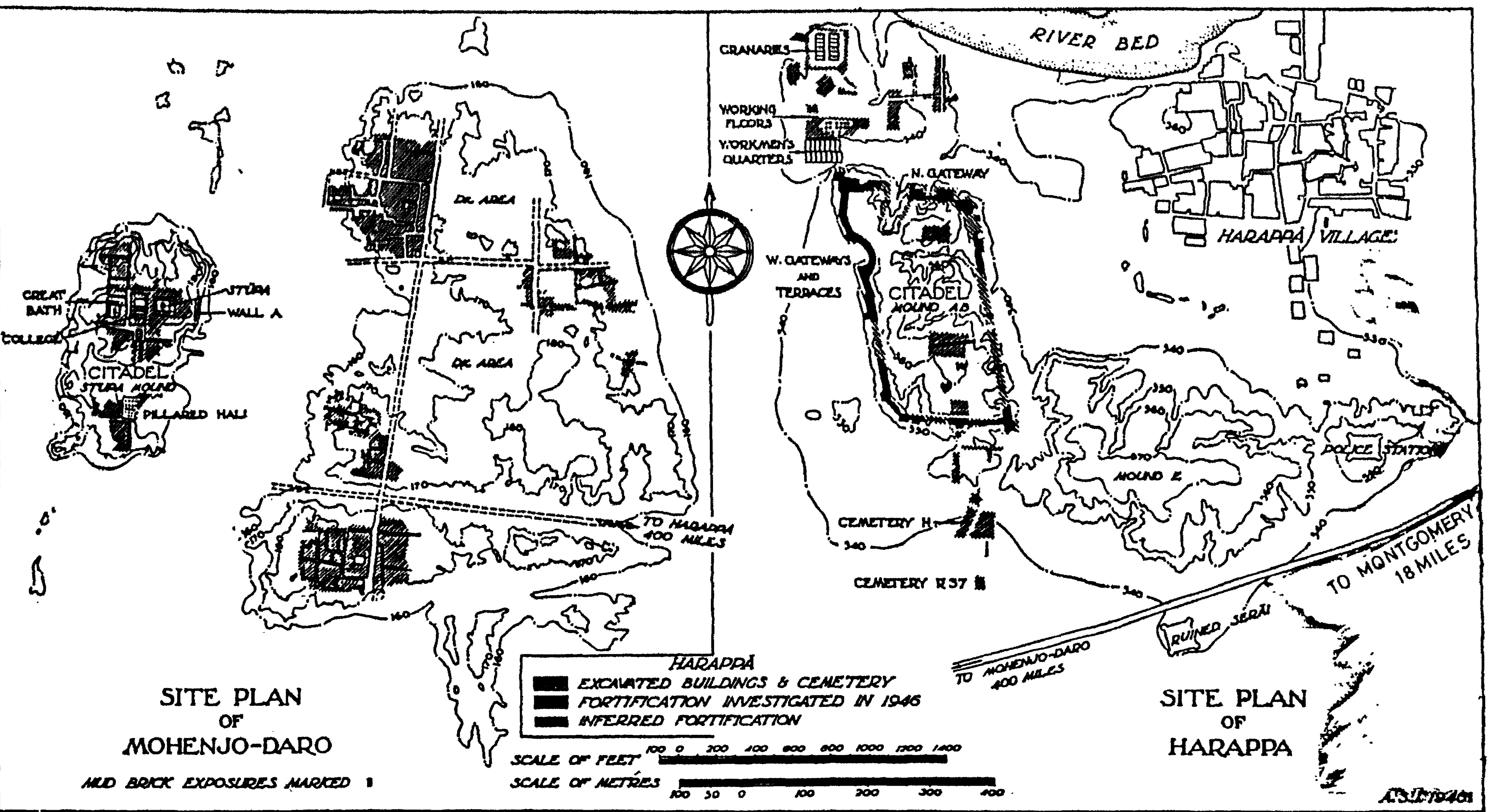


Fig. 1. Plans of Mohenjodaro and Harappa, showing township and citadel. (Wheeler, R.E.M.,1953, "Cambridge History of India, Supplementary Volume - the Indus Civilization, p.19)

towards the top (Wheeler, 1947, pp. 19-20). The core of the wall was of mud brick but it had burnt brick revetment 1.20m to 1.80m thick, externally. A sort of buttress was added internally, as an after- thought, in the form of a sloping platform of mud-brick. Bastions were erected at regular intervals and at least some of them were greater in height than the circuit wall. The main entrance was on the northern side. Evidence of guard rooms flanking the subsidiary gateways in the western wall was clear. At the southern end a broad ramp or stair led up to the citadel. Three phases or reconstructions have been identified by the excavator.

Of these, a few points are of interest in the present discussion. Of the first or original phase, the excavator states, 'as originally built the defences of the citadel long remained untouched save by weather, which wore and rounded the exposed surface of the baked brick revetment to a notable extent' (Wheeler, 1953, p. 20). The final phase or rejuvenation consisted of an enlargement of the defences on the north-east corner and the blocking off the gateway in the northern wall.

The citadel at *Mohenjodaro* was situated to the west of the township. It was raised on an artificial mound as at Harappa. Its general height was between 6.5m to 13m. From early times, the artificially raised platforms at Mohenjodaro had to be protected from floods and for this purpose a mud brick embankment of 14m breadth was first constructed. The defences of this place have not been so fully explored as those of Harappa, but whatever work has been done is enough to give a good idea of how the things must have looked like. The extent of the citadel mound was the same as that at Harappa. This was surrounded by a baked brick wall and massive towers. Out of these the earliest had to be protected from floods and hence mud-brick embankments were constructed. 'The gradual multiplication of rectangular bastions at the south-east corner cannot be fully explained without further excavation. Two of them seem to have originally flanked a postern gate which was later blocked and replaced by a platform with a parapet.' (Wheeler, 1953, pp. 28-29).

Kalibangan in Rajasthan also had two mounds, the citadel and the lower city. Of these the former is on the western side and measures 150m EW and 250m NS. Here, the lower city also had a town-wall. Its width varied between 3m and 4m ; the maximum available courses of bricks being fifteen. In the northern part at least, the town wall had been built on the box pattern, with bricks on the outer side and a mud fulling inside (IAR, 1967-68, pp. 43-44). Three possible gateways have been located and these were probably flanked by guardrooms. The citadel at this place holds unusual interest as it has preserved fortifications of two periods: Harappan and pre-Harappan. The wall was initially 1.90m thick but its width was increased to 3.70m to 4.10m during the pre-Harappan period itself. It was strengthened by rectangular bastions and had well guarded entrances. The Harappans superimposed their fortifications on these but occupied only half the area, that on the south. In the construction of these, mud- bricks was used and massive towers stood sentinel over the corners. The main gate again perhaps flanked by a bastion lay on the southernside.

Lothal on the gulf of Cambay was an important port and the city proper was well defended. A rampart of mud-brick some 4.50m in thickness and 2.30m of available height surrounded the rectangular town. These ramparts were in the nature of

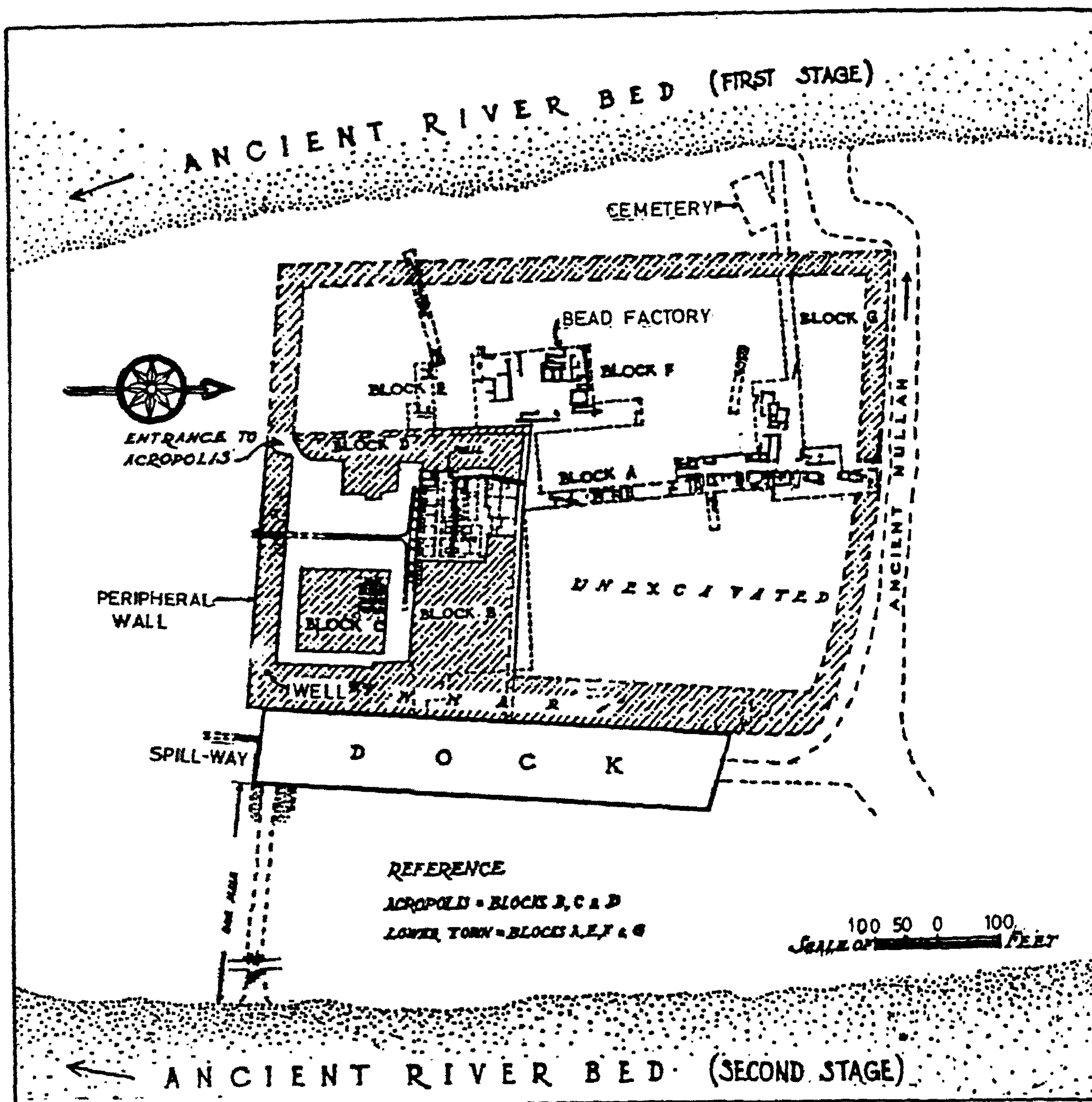


Fig. 2. Plan of Lothal, Rao, S.R., 1962, "Further Excavations at Lothal", (Lalit Kala, No. 11)

anti-flood or flood protection measures (*Fig.* 2). Within the area so enclosed, the excavator has identified a citadel with ramparts of its own (Rao, 1962, pp. 14-30).

Kot Diji in Sind (Pakistan) has preserved a pre-Harappan fortification used by or rebuilt by the Harappans (Khan, 1958) The pre-Harappan residential buildings were set against the ramparts, the latter often served as the back wall of the houses. This pattern at Kot Diji was of common occurrence at a number of Anatolian and West Asian sites of the same date (Clarke and Piggot, 1965, pp. 203-205). Very probably the Harappans followed this time-honoured practice in their citadels also.

The other category of fortified places mentioned above, can be called *fortified outposts*. Examples of these have been discovered along the Makaran coast of Balucistan in Pakistan and half a dozen places in Saurashtra-Kathiawad areas of Gujarat.

Sutakagen-Dor on the western extremity of Balucistan has been explored twice, first by Stein (1931, p. 60) and then by Dales (1962, pp. 86-92). Standing on two

separate ridges of sandstone was the usual pair of township and citadel. The latter was a parallelogram of 206m x 103m. The wall was built of huge blocks of stone, was 11m wide at the base according to Stein, and had a mud brick buttress 2.50m in thickness. The gates were flanked by massive towers. The place was situated on the estuary of the river Dasht and perhaps was intended to serve as a well protected entre' port.

Desalpur in Kutch has retained traces of a stone wall 4m in basal width and 2.50m in extant height. It has been reinforced with corner salients and towers. Huge blocks of stone, often as big as 1.5m to 1m are used in the construction. The excavators have not given the extent of the fortified area. (IAR, 1963-64, p. 17).

A small outpost, also in Kutch, was excavated at Surkotada (IAR, 1970-71, pp. 13-15). Here the ramparts were of mud and mud-brick (40 x 20 x 10 cm). For the citadel part it was 7m thick at the base and at places a rubble veneer was applied. The published report speaks of the citadel and township adjoining each other but does not mention the area covered by either. More recently at a place called Kuntasi remains of ramparts have been noticed but the excavations have progressed only partially and nothing definitive can be said.

Like their residential structures the Harappans used almost exclusively bricks - both of the sun dried as well as baked variety - for their fortifications. The walls were very thick, broader at the base and tapering upwards. Gates with flanking bastions were provided for. In many cases the ramparts served a dual purpose, defence from enemy and protection from floods. A closely countoured map of each of the places would indicate which of the two was more important from the point of the builders. Such maps are not available at present.

The weaponry of the Harappans consisted mostly of personal or anti-personal nature, swords, knives, spears, arrows and maces. Clay tablets might have served as missiles to be flung from slings - these again were anti-personal. Commenting on the nature of the arms found in the Harappan sites Mackay states, "it cannot be assumed that these (axes) were used in war, as there is no evidence that their inhabitants were ever seriously threatened by outside enemies until the last phase of the existence of the Indus cities; but they could have been used in working wood, in the chase, and perhaps against dacoits, like the little battle-axe so often carried by the countrymen of Upper Sind." (Mackay, 1935, p. 124). It is quite evident that as compared to other contemporary societies the armoury of the Harappans is most unimpressive. There is no evidence of forcible destruction of any of the Harappan fortifications. Except in the Kutch region there were no military stations or outposts and hence one has to conclude that the Harappan fortifications were local security measures, often serving to stave off floods. This also indicates that the military element was never an important aspect of Indus life.

A few of the Calcolithic sites excavated so far have revealed traces of mud-brick or mud ramparts and bunds. However, these have not been explored or exposed to an extent where their plans, strategic situation etc. could be made out. Hence for the period of circa 1700 BC to 500 BC, one has to remain satisfied by mentioning the possibility that some of early farming communities perhaps had rudiments of fortifications around them.

With the advent of the second half of the first millennium BC a much clearer picture emerges. In the first place the literary works mentioned above received their final shape during this period and must have reflected contemporary practices. Secondly accounts of foreign officials and travellers are now available. Megasthenes, who was the Greek ambassador to the court of Candragupta Maurya states that the capital Pataliputra was protected by wooden ramparts that had sixty four gates and five hundred and odd towers. Pliny/Ptolemy, speaking of the Satavahana empire state that there were thirty walled towns in their empire. Plastic representations on Buddhist monuments of this date have already been referred to above. From 1860 onwards surveys of surface remains have been extensively conducted and numerous ancient remains have been noted (*CUNN*). Over the last forty years numerous sites have been subjected to excavations. Most of these however, were vertical digs, that is, the area excavated was very small. This was mainly due to the fact that most of the ancient sites or mounds of debris are covered with modern habitations and excavations could be conducted on small plots that were unoccupied. This also limited the choice of the site for digging in a given locality. The plan of fortifications have been traced in some cases mostly through

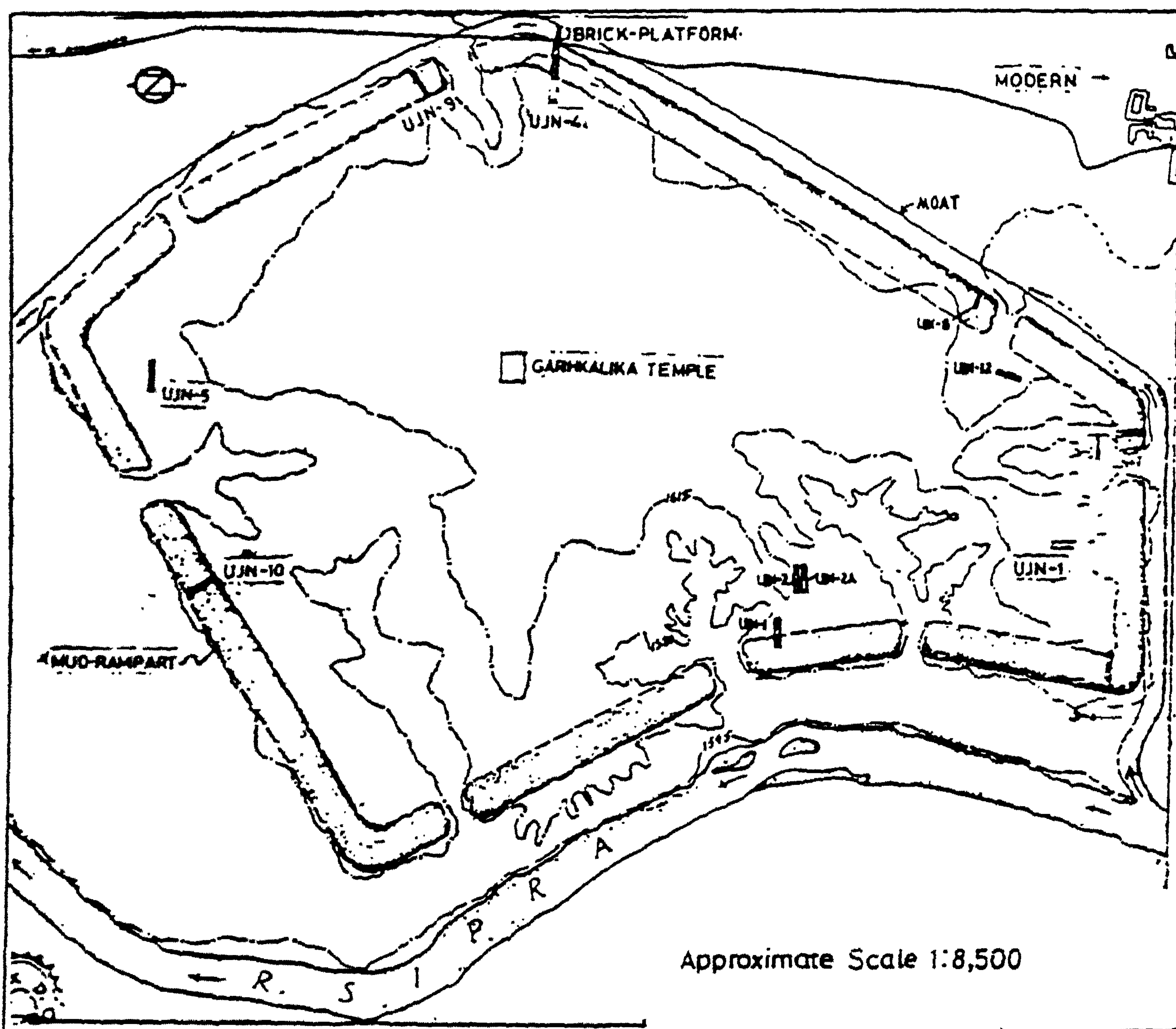


Fig. 3. Plan of Fortfications at Ujjain. ("Indian Archaeology - 1956-57; A Review", p.21, Fig.9).

contour maps and aerial photographs, but hardly ever through excavations. The picture that can be pieced together would be somewhat as under (Mate, 1970A, pp.58-69). Most of the important townships in North India were situated on the banks of rivers that supplied water the year round. These were located on natural eminences and were often flanked by small streams that joined the main rivers and served as natural barriers or moats. These towns were enclosed within gigantic ramparts mostly consisting of heaps of earth and sometimes of sun dried bricks. Ramparts at Ujjain (*Fig. 3*) had a basal width of 60 to 75m and the extant height was 12m while the moat surrounding the wall was between 27.50 to 45m broad (IAR, 1955 to 1958). This was lined with baked brick where danger from floods of the river was apprehended. At Kausambi the average height of the rampart was 10.50m to 12m but the basal width is not mentioned in the published report.

Free standing towers some 22m in height were a special feature of the defensive system at this place (*Fig. 4*). There were eleven gateways and at a later stage baked brick revetments were provided for. These were in 140 courses (Sharma, 1960, pp.27-40). Other places like Rajghat, Vaisali had earthen ramparts around them. At Ahichatra this earthen wall was topped by a brick wall of 3m height and 'to economise in brick it was built in blocks, the intervening spaces being filled with rubble and clay. Its width was 4.88m (IAR, 1963-64, p. 44). In a number of cases the foundation of the earthen ramparts was strengthened by placing huge logs of wood in piles at the base. Ujjain has yielded the best example in this regard (IAR, 1957-58, pl.XLI). The so-called palisade of timber uncovered in the excavations at Pataliputra poses more problems than it solves. It is often cited to support the statement of Megasthenes that there were wooden ramparts (*Fig. 5*) round the town. These palisades really seem to form a long tunnel or reinforcement over which the earthen ramparts were built. In that case Megasthenes could not have seen them, the only possible explanation of his statement seems to be that instead of brick parapets as at Ahicchatra wooden parapets were erected over the earthen walls. With the possible exception of the so called War of Relics' which is depicted as having taken place below the ramparts of a number of towns, no important battle in ancient India had taken place below or around a fortified town.

There are hardly any descriptions of a siege or siege-warfare from this period. The geographical location and the stupendous size of these ramparts around the towns of north India, especially the Gangetic valley make it appear that they were flood protection measures.

There are places like Rajgir, in Bihar, Śiśupālgarh in Orissa which have got an essentially military or defensive purpose. Rajgir or Rajagrha or Girivraja was situated in a valley surrounded almost completely by hills and sometime in the sixth-fifth centuries BC a rubble wall of 'considerable height' running atop these hills was erected. Its circuit was twenty five miles. Nearer the township, clay and rubble ramparts were erected and the perimeter was five miles. This was in the 4th century BC. The site was deserted in the latter part of the century in favour of Pataliputra. (Ghosh, 1951, p. 66). Far more convincingly defensive or military in purpose was the site of Sisupalgarh (*Fig. 6*). It is a rough square on plan, each side approximately 1.40 km with a tower on each corner and two gates in each side. These were flanked by guardrooms. Somewhere in the third century BC this

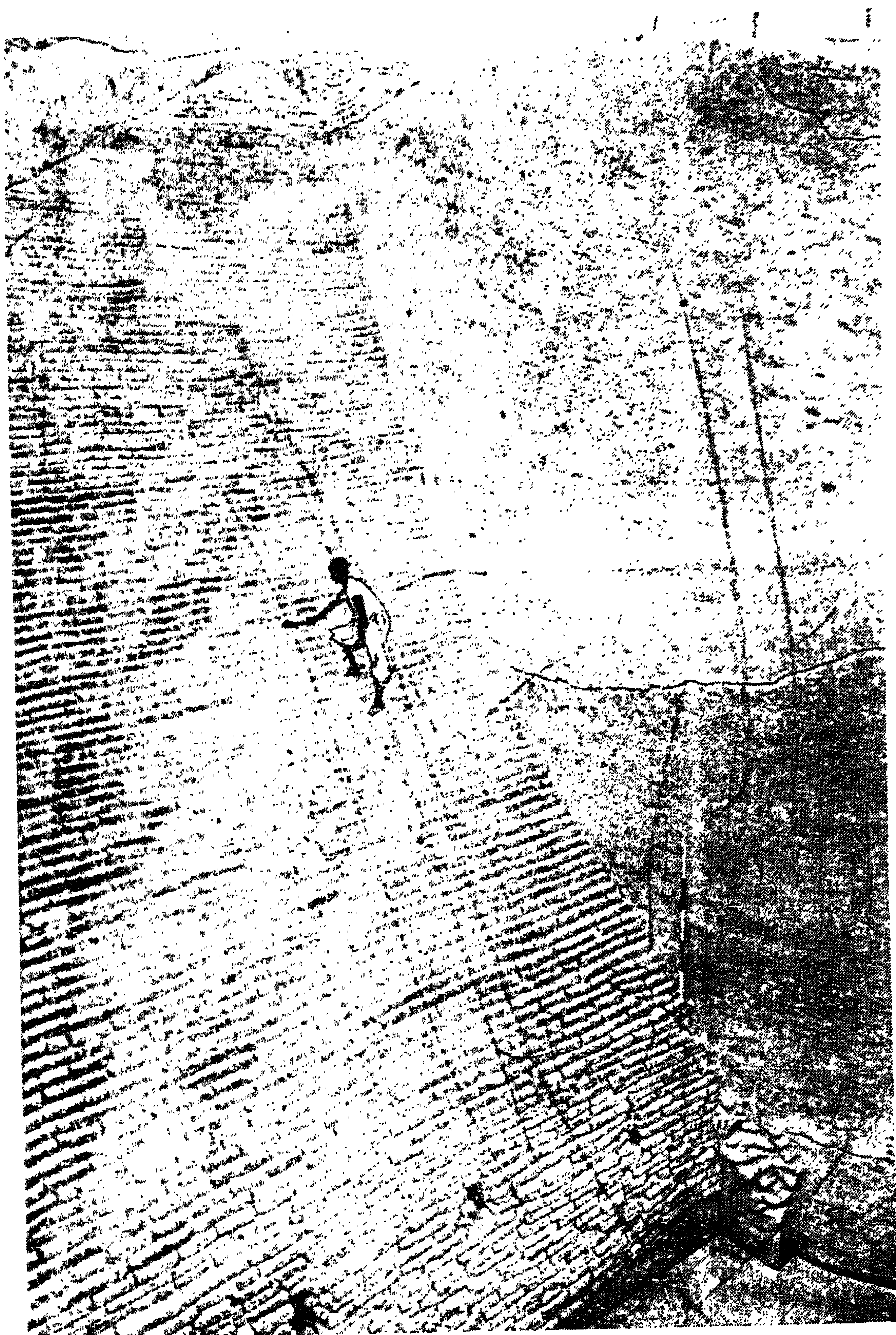


Fig. 4 Photograph of defences of Kauśāmbī. ("Indian Archaeology - 1957-58, A Review", pl. LX).

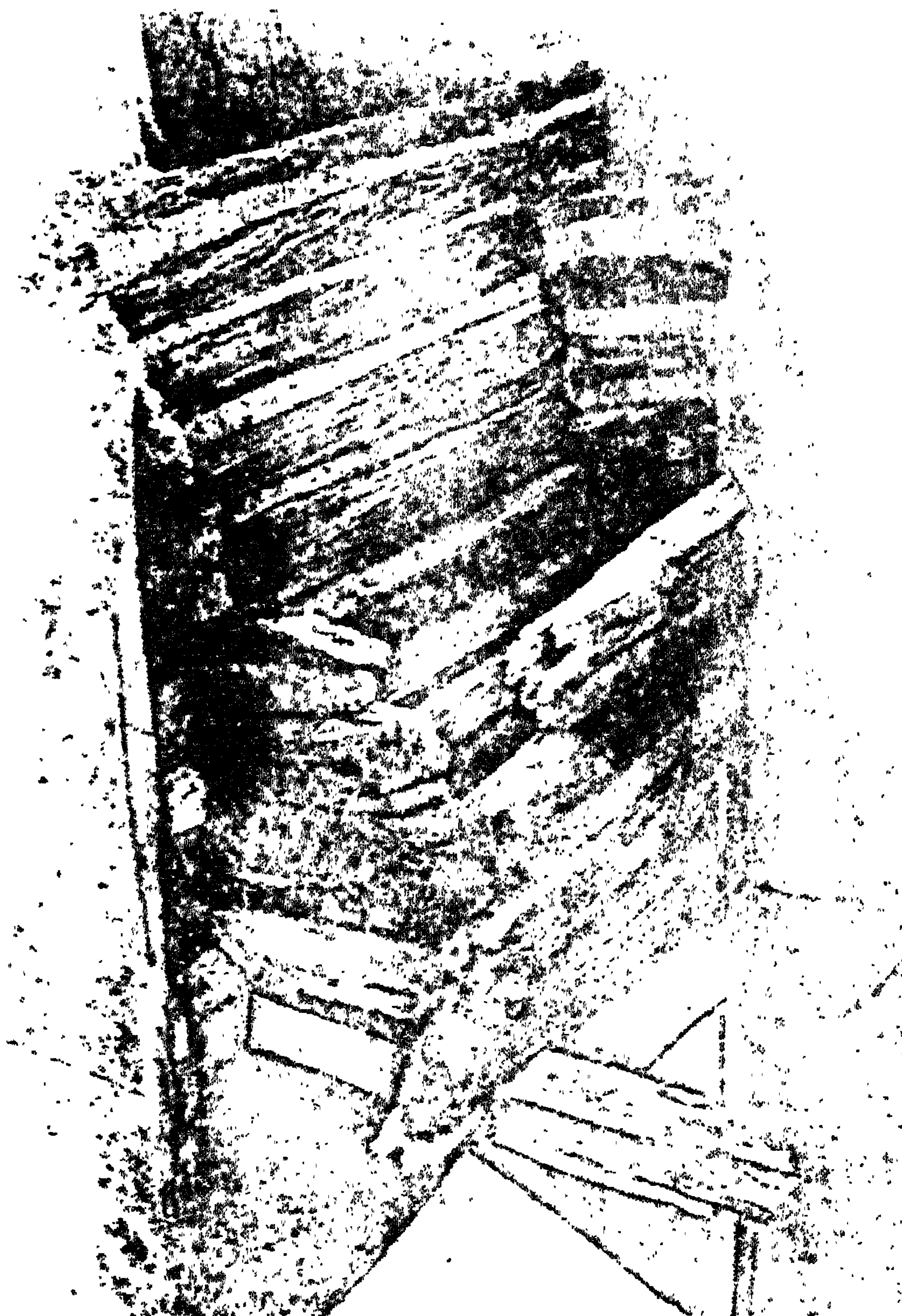


Fig. 5 Photograph of wooden construction in the make up or the ramparts. ("Indian Archaeology - 1957-58, A Review", pl. XLI A).

rampart of clay with a basal width of 110 feet and twenty five in height was erected. In the second phase of construction a 4′.6" thick covering of lateriate 'gravel' was added over the clay base, and subsequently a baked brick rivetment was provided on either side or face of the mud rampart. The fortification served the town for well over seven centuries, was kept in a constant state of repairs. The whole area was surrounded by natural streams 'one of which was diverted for the purpose' (Lal, 1949, pp. 62-78).

Towns and cities in Southern India slightly later in date than the Ganga valley fortifications were surrounded by town walls and ramparts. A number of places, more especially in Andhra Pradesh, like Satanikota, Dharanikota have been explored and partially excavated to reveal town walls. It was however, Nagarjunakonda that gave a detailed picture of defensive architecture as practiced in the South (*Fig. 7*). Two separate areas, both surrounded by protective walls were revealed during the explorations. The one on the northern side enclosed a large Buddhist vihar-cum-caitya area, consisting of a number of stupas and vihāras (*Fig. 8*). The walls around these were renovated, strengthened and enlarged often but it remained an enclosure wall and nothing more. On the southern side a trapezoidal



Fig. 6 Aerial photograph of Śiśupālgarh. (Ancient India, No. 5, pl. XXVII).

area 900m × 750m referred to by the excavators as the Citadel, had fortifications proper. The southern side of this area was protected by the Pedakundelgutta hill with an average height of 170′. On the other three sides was a moat 12′ in depth and between 74′ and 132′ in breadth, fronting the ramparts. The maximum extant height of these ramparts, above the surrounding plains is 16′ and they run along the ridge of the hill on the southern side. The excavators had noticed two phases; in the first phase a rampart of rubble and earth was constructed with a basal width of 80′; in the second phase a wall of baked brick 9′ to 14′ in thickness was built over the earthen rampart.

Two gateways, one in the western side and the other in the eastern side were cleared; a small entrance was also noticed on the northern side. Very probably guardrooms or barracks were placed inside the eastern gate. There were no turrets or bastions anywhere along the wall or near the gates. The entire fortification is placed in the 3rd-4th centuries AD.

It would be observed that unlike their counter-parts in the north, the ramparts in the southern sites are smaller in size. This possibly was because the absence of the

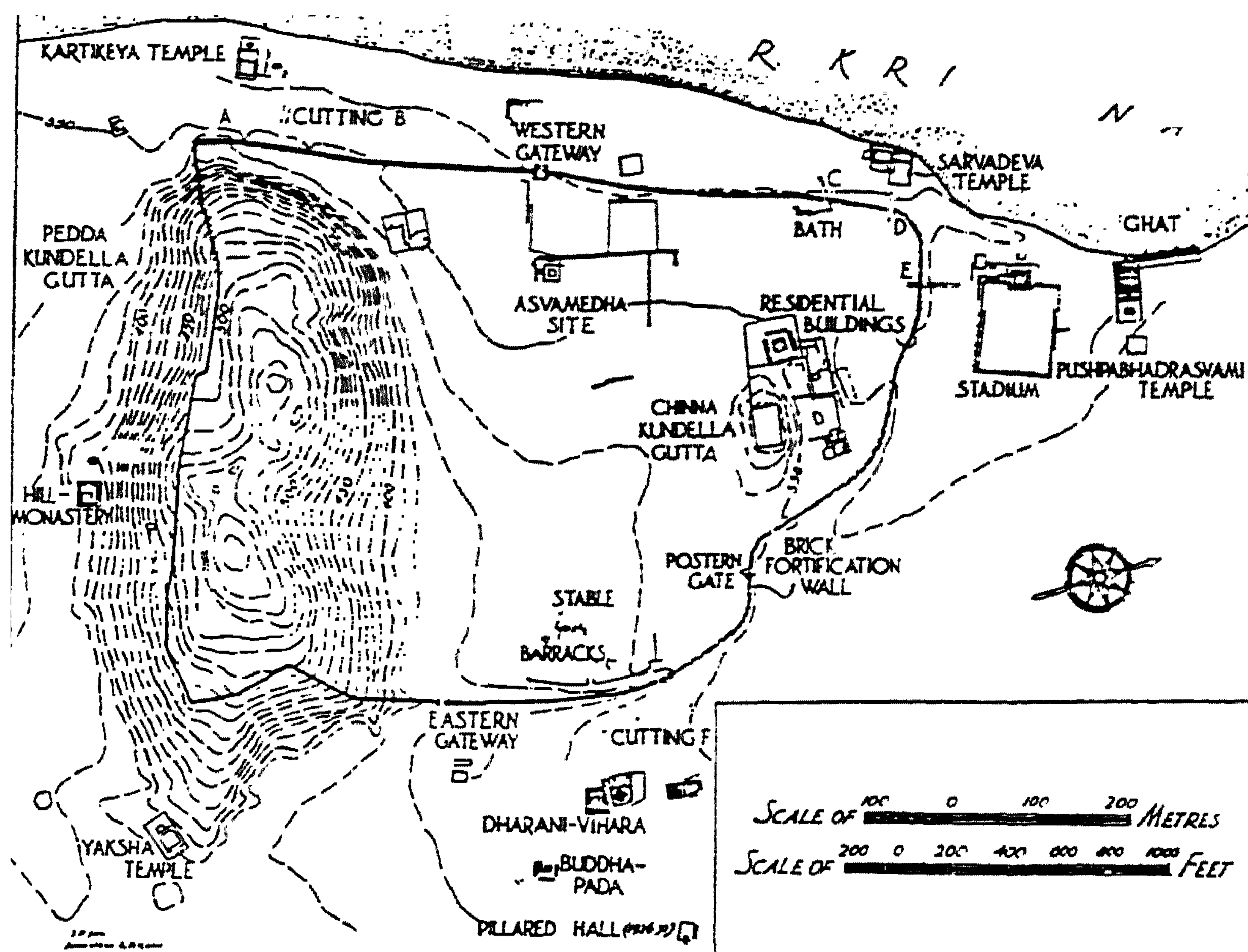


Fig. 7. Plan of Fortifications at Nāgarjunakoṇḍā. ("Indian Archaeology - 1957-58 ; A Review", p. 7).

danger of massive floods in the case of the southern cities, which the cities in the north constantly faced. As such the fortifications around the southern cities could be treated as defensive or military measures.

The rise of the Gupta dynasty and its equally illustrious contemporary, the Vakatakas in the fourth century is usually regarded as the Golden Age of Indian Culture. The uncertainty following the repeated incursions of the various Saka and Kusana tribes was put to an end. The Ganga basin to begin with and then most of the country north of Narmada was pacified and brought under imperial control by successive Gupta rulers. The records of Candragupta II and Samudragupta narrate that story and it needs no repetition here. It is to be noted that the rise of the Guptas was facilitated more by mutual understanding, often resulting in matrimonial alliances between the small regional kingdoms and tribes like the Nagas of Central and Northern India. It was more a process of consolidation and recognition by equals that one among them was superior to the rest.

It was in the later phase that military element crept in, but that was outside the core area of the Gupta empire. The Vakatakas had friendly relations and matrimonial relations with their northern neighbors and in general, the political climate appears to be peaceful; consequently the need for constant military preparedness, in the nature of fortifications, seems to have become less pressing than in the previous age. This era of comparative tranquility came to an end by the

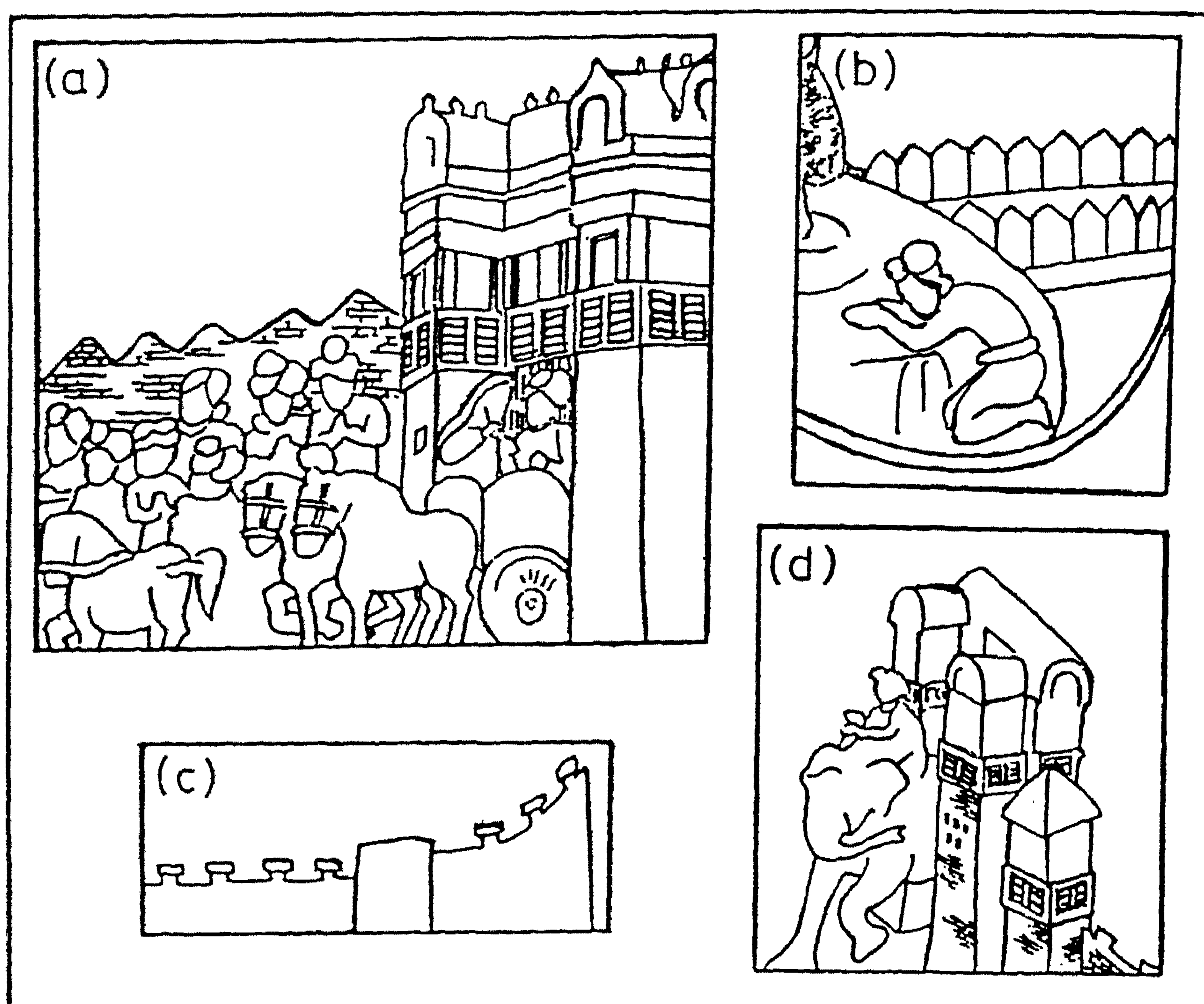


Fig. 8. Representations of fortifications in Sculpture. Mate, M.S., 1970A.

closing decades of the fifth century and once again 'region-based' kingdoms and dynasties started asserting themselves. There was no dearth of claimants to the imperial mantle of the Guptas but few were in a position to assert their superiority over others in terms of military might. This situation continued well upto the eleventh century, perhaps slightly beyond. These region-based kingdoms were not necessarily small and by the seventh century a well established pattern emerged - the Pala-Senas in Bihar-Bengal; the Śaśāṅkas in north and the Candellas in south U.P.; the Pratiharas in the Rajasthan area; The Traikutakas and Kalacuris in the Narmada area; the Calukyas in north Karnataka and the Pallavas in the extreme south. In terms of fortifications it meant that so many frontiers were created and had to be protected. Additionally trade and military routes, important cities and capitals had to be taken care of, thereby multiplying the places to be fortified.

Literary records of this period, both of the Puranic variety and the scientific variety - sastras - speak of forts, their classes, locations etc., indicating greater and renewed interest and activity in the field.

Ironically it is this period which has received little attention from archaeologists. The surveys carried out by Cunningham in the last century supply whatever reliable information that we have. Occasional excavations at a number of places, which were more a matter of unavoidable effort as the excavators wanted to reach lower levels, supply additional information which at best is sketchy. The paucity of firm

data has obscured the picture. To add to the confusion is the fact that many of the forts like Citorgarh or Kalanjar originally erected in the period under reference have been reused, renovated, remodelled, and alterations carried out by the succeeding Islamic rulers of the post-12th century period. This has in most cases obliterated the original fortifications, except perhaps the locations and the general plan, thereby limiting our ability to isolate and understand the art of fortification of the pre-11th century period. However, the picture is not as bleak once we turn to the Deccan and South India. Here the earlier traditions seem to continue, with a difference whereas north Indian townships continue to have earthen ramparts around them, those in the former area have started using stone.

Mahasthangarh (Bengal) was a small plateau measuring 1.37 km × 1.22 km rising to a height of 4.50m over the surrounding plains. There were broad and deep moats on the north, south and west while the river Kartrya defended the eastern side. The corner bastions rose to a height of 10m and gates were provided for in all four directions.

The city wall was 3.35m in thickness and 3m in extant height, both faces built of burnt brick and the core filled with brick- bats and mud. The introduction of semi-circular bastions is an intriguing feature. This place was identified as Paundravardhan, the capital of the Varendra kingdom and its antiquity went back to the 4th century B.C. But its close association with the Guptas is indicated by numerous coins of Candra Gupta II and Kumaragupta, as well as by the ruins of a temple of the Gupta period (*CUNN*, XV, 104-117 and *ANRSI*, 1928-29, 1930-34, p. 128).

The castle of Mandor or Junagarh in Rajasthan (*CUNN*, XXIII, pp. 73-85 and *ANRSI*, 1909-1910, p. 100) stands on a rock or hill. It is surrounded by a moat and the eastern and southern sides of the rock are almost vertical, like a scarp. The walls are built of massive squarish blocks of stone put together with lime-mortar or any other cementing material. Perhaps the use of such massive squarish blocks led to another feature found in most pre-Islamic forts, squarish or rectangular bastions and turrets. The height when Cunningham surveyed it was 7.62m. A few circular bastions were added during the subsequent period.

The Candellas of Bundelkhand were reputed to have eight mighty forts in their possession. These were supposed to be 'boundary forts' that protected the frontiers of their kingdom. The eight that are usually named are : Bairagarh, Kalanjara, Ajayagarh, Mahiyarh, Marpha, Mandha, Kalpi and Garka. Some lists substitute the names of Mahiyar or Kirtigiri for Kalpi.

Among these forts, Kalanjar was the most important, a sort of heart of the military might of the kingdom. It is a hill more or less detached from the main Vindhya ranges and stands to a height of 245m above the surrounding area. The plateau on top is oblong in shape and the fort wall runs all around it, measuring 6.4 km in length. A number of gates, loop-lines, bastions are encountered in the ascent to the top but these were in all probability additions during the Islamic period. (*CUNN.*, XXI, pp. 20-28; *ANRSI.*, 9127-28, pp. 1112).

Ajayagarh (*CUNN*, VIII, pp. 46-49 and XXI, pp. 46-48) has a similar story to tell except that its natural location is much stronger as the natural scarp all around the top makes it almost totally inaccessible. The selection of hill tops from which

surveillance over a vast surrounding area was possible and which were never easy of access are the main features to be noted in these forts.

Badami in Karnataka, the capital of the early Calukyas had a fort, the date of which is uncertain and shows signs of extensive renovation during the 16th - 17th centuries.

Aihole in Karnataka, the temple city of the Calukyas and Alampur (A.P.) had till recently preserved traces of town-walls and gates. These were built of fairly large blocks of stone laid without mortar. The walls were generally three to four meters in thickness and equal in height. The gates were of the pillar and lintel variety, more like the Buddhist *toraṇas*. Such ramparts served quite well so long as the defenders faced weapons like javelins, arrows or sling-balls. But with the introduction of gun-powder a number of changes became necessary.

The defenders had to cope with a much greater destructive impact, higher trajectory and greater range. The answer was, much thicker and mortar bound walls, greater heights and extension of areas covered by ramparts so as to keep artillery as far away as possible.

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Structural Principles In Temple Architecture

KRISHNA DEVA

A connected history of temple architecture in India commences from the Gupta period (c. 4th-6th centuries A.D.) when temples of brick or dressed stone started being constructed on the logical principles of structural architecture. The early Gupta shrines were flat-roofed structures comprising a square sanctum and a small pillared porch. An elaboration of the plan by addition of *maṇḍapa*(s) and covered ambulatory and of the elevation by addition of *śikharas* (spires) over the sanctum and the *maṇḍapas* was effected gradually. As the centuries rolled by, the temple developed complex forms both horizontally and vertically together with regional accents which manifested themselves quite early but matured slowly and became quite distinctive by the 10th century A.D. As India has a rich wealth of good building stones and a network of rivers to facilitate their easy transport from the quarries, the stone temples far exceeded those of bricks. We shall, therefore, talk here mainly of stone temples which best represent the flowers of evolved temple architecture.

As a rule, the Hindu temple pertains to the trabeate order which is based on the principle of compression, with its superstructure raised on the system of post-and-beam. The seemingly domical or arch-like ceilings are all false and feigned and are devised on the method of corbelling (*kadālikakaraṇa*) or interlocking of courses, plain or carved.

Normally a well-settled, firm and hard site was selected for the temple construction after carefully examining its geological composition and physical configuration by putting the ground to several tests for its stability, compactness and proper slope. A rocky and elevated site always received the first preference since it did not need any deep foundation.

But if a temple had to be constructed in the plains, a foundation equal in depth to the height of the *adhiṣṭhāna* (base) had to be dug which normally varied from 6 to 8 ft. A foundation pit, coextensive with the dimensions of the temple, was dug and filled with bricks, earth and sand and packed tight by being stamped down by the trampling of elephants and heavy logs of wood. The horizontality of the foundation bed was maintained by measuring water level and after compacted bed

reached a reasonable height the initial mouldings of *upapīṭha* and *pīṭha* resting on one to three plain slab-courses were constructed. Usually the *upapīṭha* was concealed under the ground and only the *pīṭha* was fully or partly visible above the ground and this supported the main mouldings of the base proper (*vedibandha* or *adhiṣṭhāna*).

The canonically prescribed structural parts with fixed proportions of the basal architectural members and their constituents have a spread out group of mouldings which grip the ground or the platform terrace and provide a firm base for the superstructure including the wall and the spire. The wall upto the waist rises almost vertically while the supervening *śikhara* shows a pyramidal or conical outline gradually diminishing to a point constituting the finial. Thus the temple structure has a built-in stability with a sprawling, broad base, a vertical wall and a superstructure tapering to a point.

The ancient architect, who was also a trained engineer besides being a good painter, sculptor and expert in the religious lore and various branches of the *Śilpaśāstra*,supervised and guided all the operations connected with the temple construction from the quarrying of stones of the right texture, shade and consistency through their sculpting and carving and setting in proper positions. The quarried stone blocks were rough-dressed at the mines and transported to the temple site where they were initially sorted out in two broad divisions: 1) those meant for the core or hearting which required simple dressing, and 2) those intended to be used as face-stones, which had to be fine-dressed, carved and suitably finished to specifications and placed in separate groups for each structural member and its constituents.

After the foundation was laid to the required depth taking into account the nature of the subsoil and the ground as well as the total load and dimensions of the proposed edifice, the structural frame was built with hearting stones. These were simple dressed blocks, laid dry, one upon or against the other in staggered courses after breaking the joints, so that their rough surfaces coming in mutual contact interlocked and held together without the risk of sliding. These courses were compacted largely by their weight and balance and were often also jointed by stone-pins or iron-dowels.

The sculptures in the round, generally meant to be enshrined in the temple, were fewer and presented no problem. Those that were carved in relief, whether low, medium or high, were more numerous and had to be sculpted together with their back-slab and were required to conform strictly to size and dimensions to fit into the marked slot or position in the niche or the wall or any other part of the temple structure.

The face-stones, whether decorated or plain, were fitted in plumb and the gaps, if any, between them and the heartings were tightly filled in by stone blocks or chips of suitable size. The face-stones were usually coursed and care was taken to break the joints with the underlying as well as the overlying courses. Further, the facing courses were bound together by the scarf or other carpentry joints to ensure stability.

It was certainly easier and more expedient to prepare sculptures or carvings on the ground and then fix them up to the structure. But sometimes problem arose

when a sculptured wall juxtaposed or met the surface of another sculptured or carved member. In such cases coordination at the junction became often difficult and one or the other had to be partly concealed or sacrificed, as seen sometimes at the junction of the sculptured wall and the projecting *kakṣāsana* of the exterior on temples such as those at Khajuraho.

Each compartment of the interior of a medieval temple had its own ceiling supported on beams and architraves resting on walls, pillars or pilasters. While the minor compartments had usually flat (*samatala*) ceiling, usually relieved by lotus design, the ornate ones are normally of two types - 1) the lantern type made of diminishing intersecting squares, and 2) the cusped and coffered type with a number of sub-types.

The simpler cusps resemble ribbed tiles while the ornate ones resemble floriated shells with serrated petals often terminating in adoring figures of *nāgas*. The larger ceiling of the main *maṇḍapa* is carried on a square framework of architraves supported on four central pillars, each with an attic (*ucchālaka*) section. The square ceiling is first turned octagonal by cutting the corners and finally made circular. The circular ceiling consists of a number of concentric courses (*nābhicchanda-vitāna*) with the outer rings of simple cusps and the inner ones of coffered cusps. The smaller ornate ceilings over other compartments have many varieties and forms, circular, elliptical and square, with five to nine or even more such concentric units of simple and coffered cusps, often with a central pendant of staminal tube (*padmakesara*) which may resemble that of the hibiscus flower or a simple pinecone or even a grand chandelier as in the famous Jain temples on Mt.Abu. These ceilings, built by the devices of corbelling and interlocking of courses reveal remarkable ingenuity and artistry on the part of the architect.

The brackets and struts, adorned by three-dimensional figures of *vyālas* (leogryphs), *śālabhanjikās* (tree and woman motif) and *surasundarīs* (nymphs) in the interior, constitute an attractive feature of the ornate temples like those at Khajuraho by their sensuous modelling and exquisite finish. But they share no load at all and are merely ornamental being fixed by the device of mortice-and-tenon to either the pillar brackets, generally decorated with atlantid figures, or to the corners of the ceilings.

A special feature of the developed medieval style is its tall *śikhara* clustered by numerous *aṅga-śikharas* which emphasize its vertical accent. The problem of erecting a tall and massive *śikhara* without adding much to the load was cleverly solved by the Khajuraho architect by building a series of hollow chambers of diminishing width above the sanctum. For this, recourse was taken to putting up in the interior walls of gradually narrowing width over offsets and strengthening the walls of the resultant hollow chambers by erecting tie-beams at intervals, as seen in the published sections of the temples. While the pyramidal (*phāṃsanā*) roof of each *maṇḍapa* has normally one such hollow chamber, the tall Nāgara *śikhara* over the sanctum indeed had to have a series of them. A similar device is followed in other regions.

Each constituent of the plan and the elevation had a certain set measure and proportion to all other parts of the temple structure, fixed by canon or traditional practice. The earliest surviving *Śilpaśāstra* which provides such prescriptions is

the *Bṛhat Saṃhitā* of Varāhamihira of the early 6th century AD. According to this text the height of a temple should be double its width and the portion upto the *kaṭi* (waist) should be 1/3 of the total height. The internal width of the sanctum should be 1/2 of its external width. The width of the doorway should be a quarter of that of the sanctum while its height should be twice its own width.

The height of the main image or *liṅga* under worship should be less than that of the doorway by 1/8. The ratio between the image and the pedestal should be 2/3: 1/3. Most of these measurements and ratios tally with the Gupta temple at Deogarh (Distt. Lalitpur) of early 6th century and the Muṇḍeśvarī temple (Distt. Rohtas in Bihar), dated A.D. 636. The exact correspondence between the canonical prescription and the architectural practice is aptly illustrated by the Muṇḍeśvarī temple whose octagonal sanctum measures just 40 ft. externally and 20 ft. internally in the prescribed ratio of 2:1. Similar is the Paraśurāmeśvara temple of 7th century at Bhubaneswar whose sanctum is 18 ft. externally and 9 ft. internally. Further, the proportion of the height and width of the doorway in relation to the sanctum has almost faithfully adhered to the canonical regulation through all ages.

For medieval temples of North India two standard Śilpa texts are the *Samarāṅgana-Sūtradhāra*, an early 11th century work from Malwa, and the *Aparājitapṛccha*, a late 12th century work from Western Rajasthan-Gujarat.Of the two texts, both of encyclopaedic character with similar contents, the latter is more practical and informative and is still made use of by the Somapuras, the traditional architects of Gujarat.The *Aparājita* provides detailed instructions of the minutest parts of the temple structure with their relative ratios,of which a few may be cited here as samples. It lays down that the *jagatī* (platform terrace) should be broader than the main temple structure by at least 1/3 and its height is to bear the following ratio :

Height of temple	*Height of platform-terrace*
upto 15 ft.	1/2 of temple
16 - 30 ft.	1/3 of temple
31 - 75 ft.	1/4 of temple

While these prescriptions are applicable to structures upto 40 ft. high, no standing temple is available with a platform terrace taller than 12 ft. At Khajuraho the height of platform terrace generally ranges between 10 and 12 ft. for temples as high as 60 to 100 ft.

The *Aparājita's* regulation for the relative heights of *pīṭha* (socle) and the *prāsāda* (entire edifice), however, are more realistic. The approved ratio of *pīṭha* and the edifice are briefly indicated as follows :

Height of temple	*Height of pīṭha (socle)*
upto 15 ft.	less than 2 ft.
18 ft.	3 ft.
54 to 75 ft.	$4^1/_2$ ft.

Though the *pīṭha* is said to be an optional member, it is mostly present on medieval temples of all schools in Central India, Rajasthan and Gujarat from early 11th century onwards. The three essential mouldings of the *pīṭha*, viz.

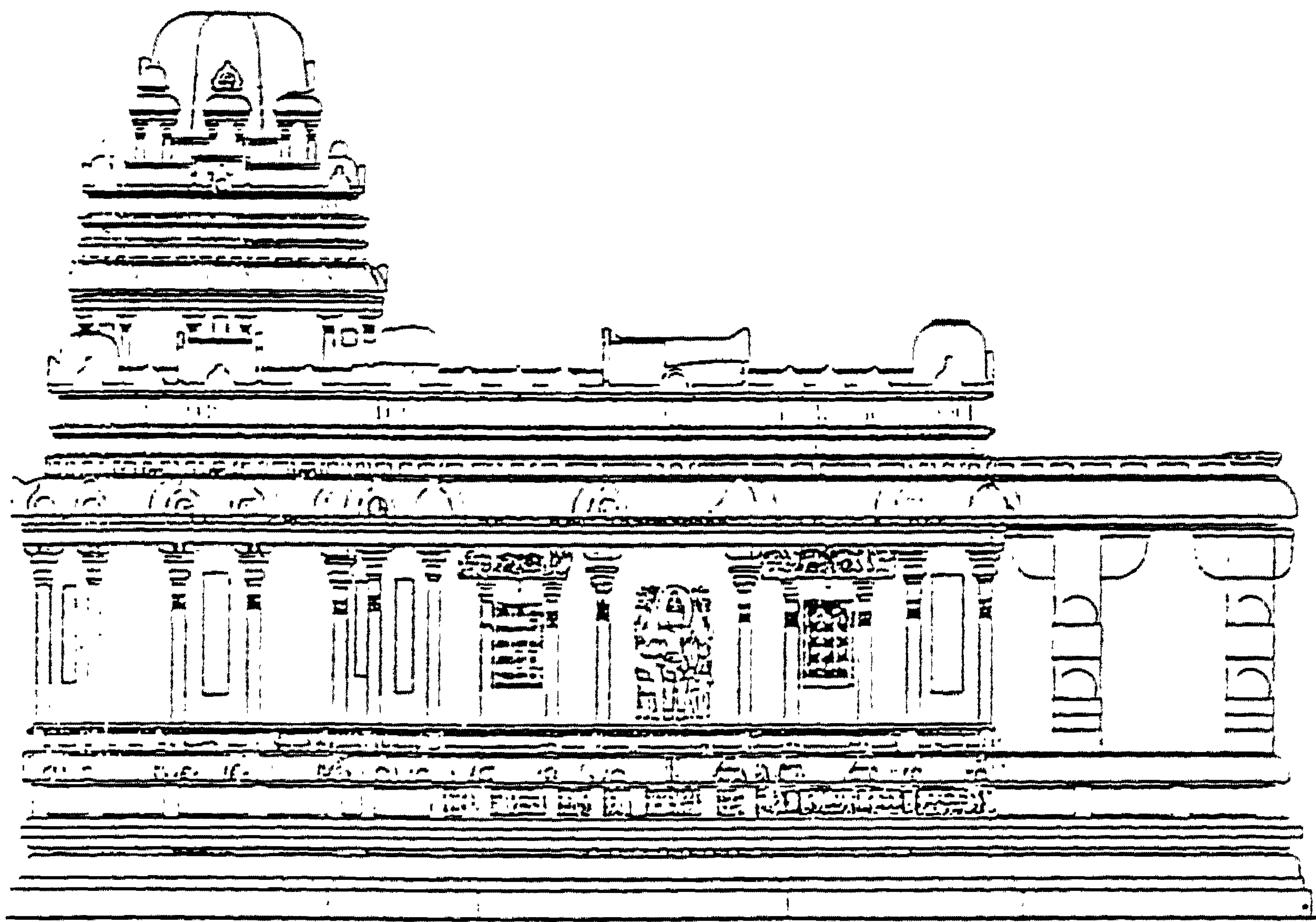


Fig.1. Bādāmi. Malegitti Śivālaya, Elevation. (Early Cālukya style, A.D. 655-860).

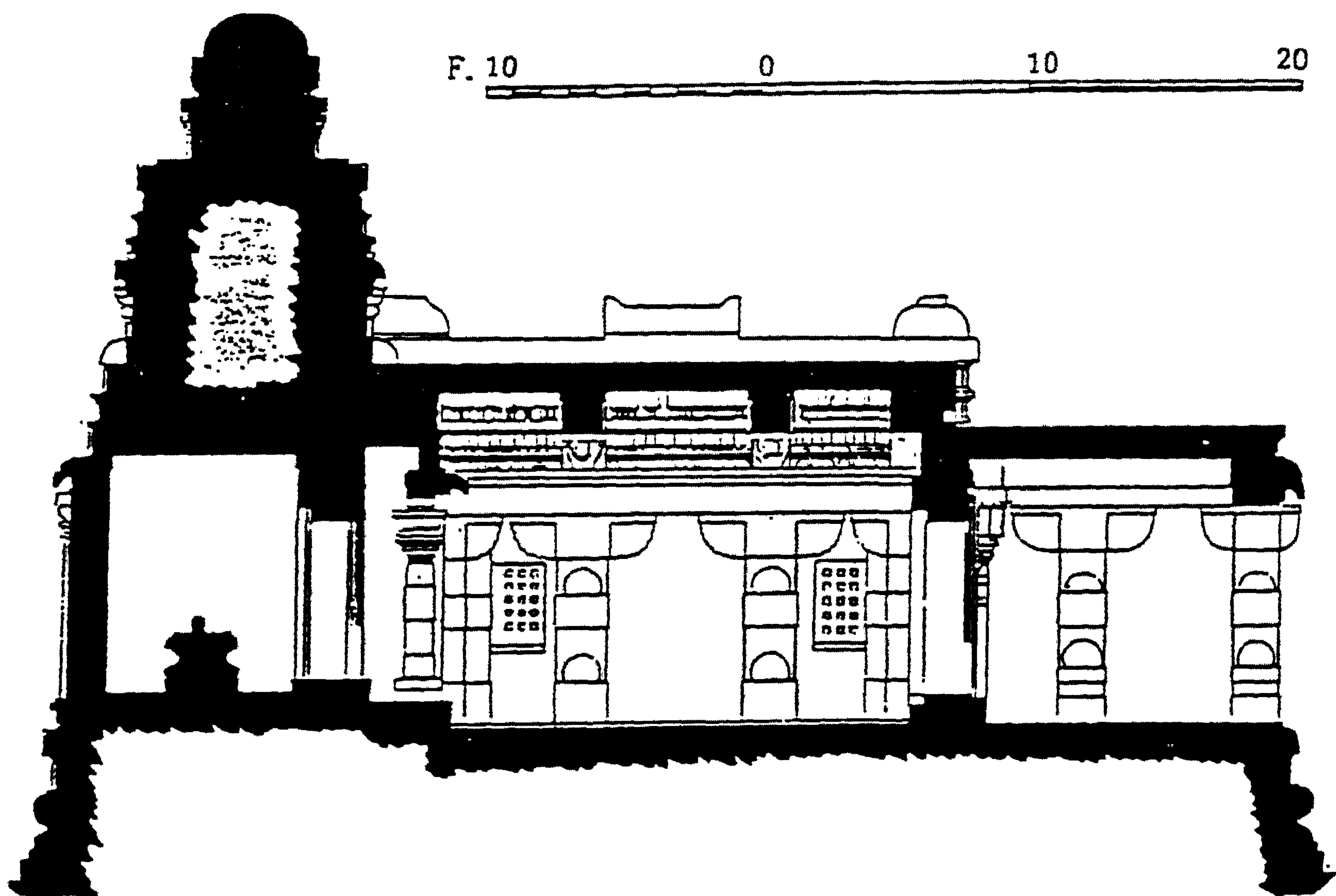


Fig.2. Bādāmi, Mālegitti Śivālaya, Section.

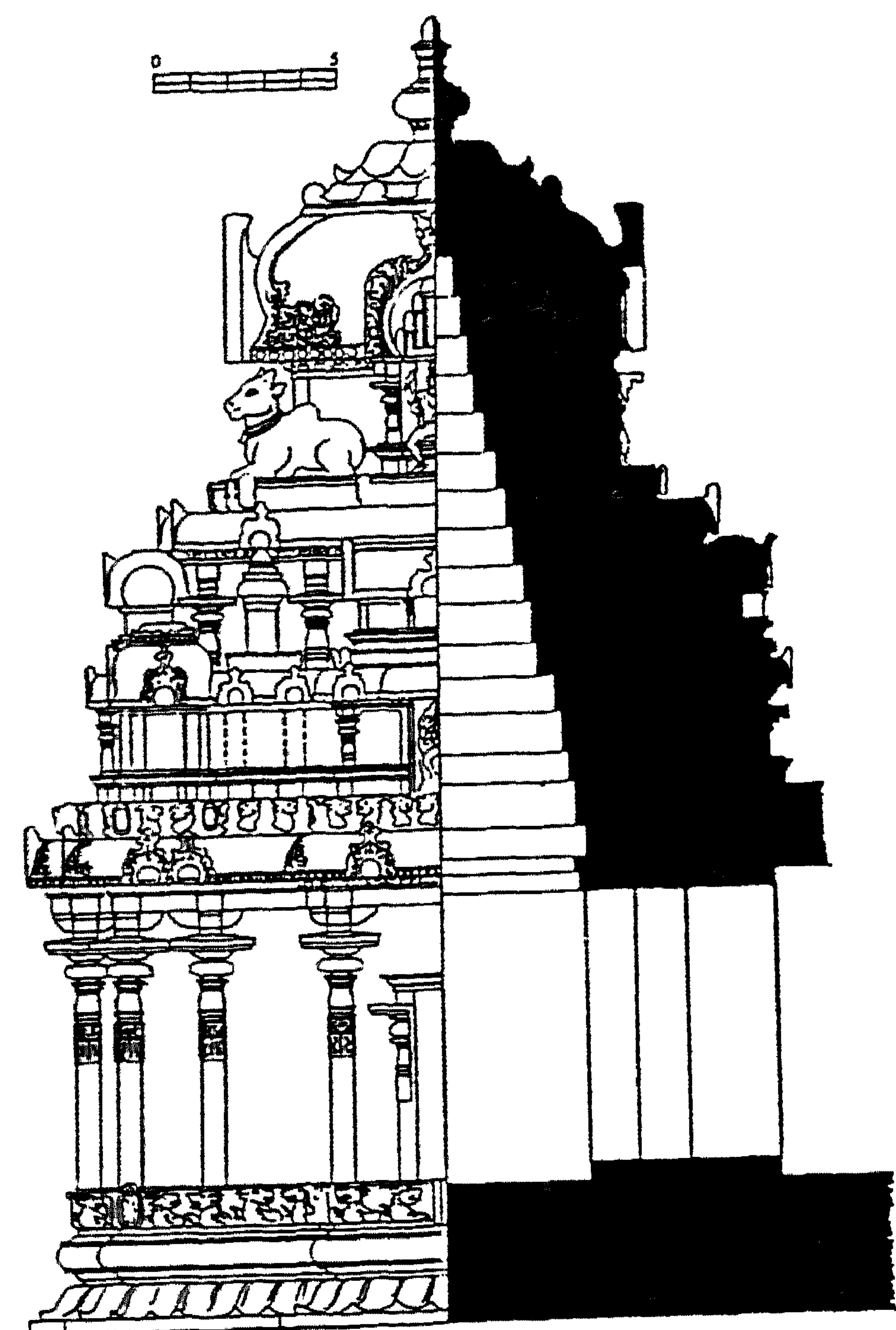


Fig.3. Koḍumbālūr. Mūvar Kovil, Section & Elevation. (Dravidian style, AD 880-900)

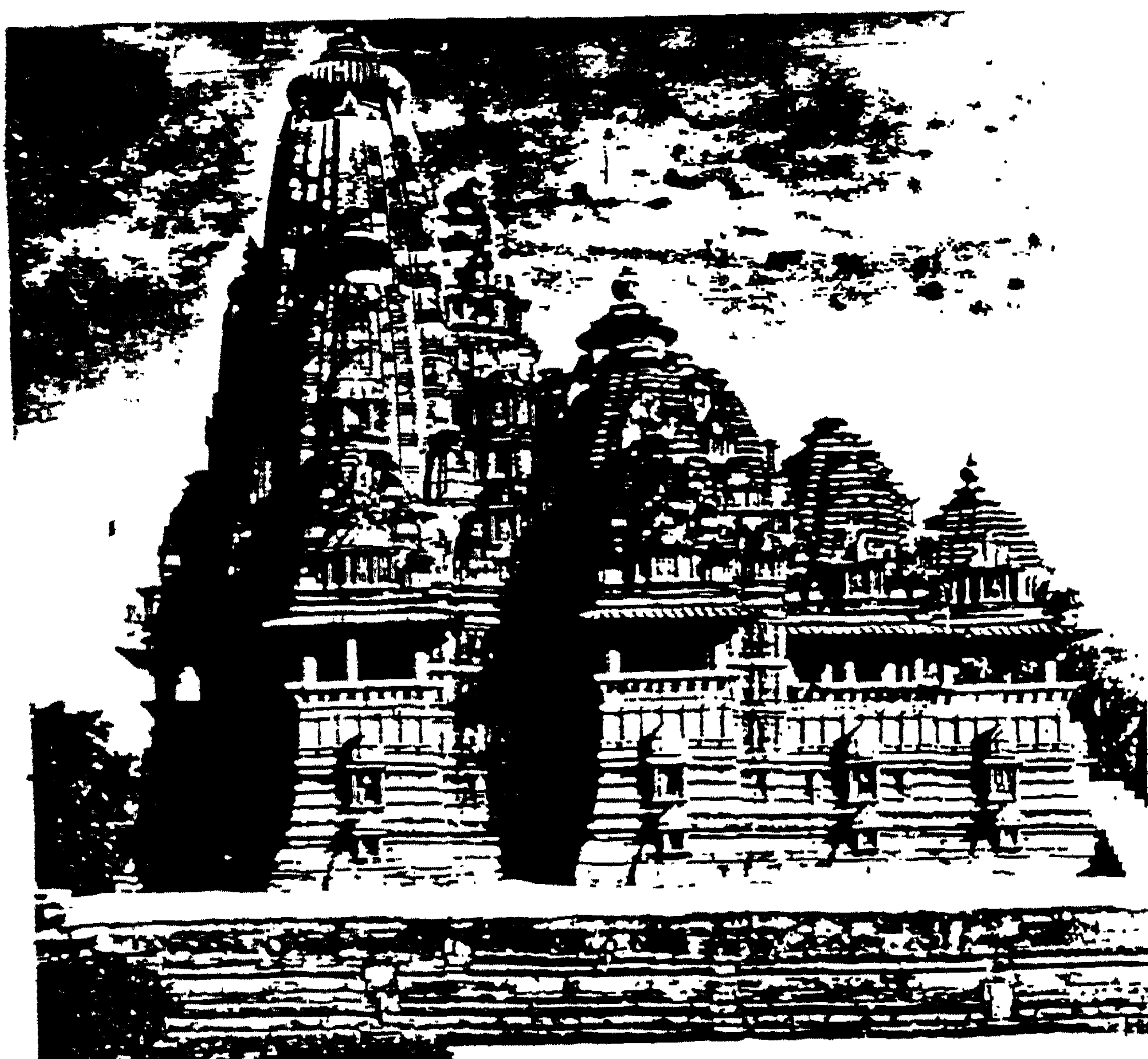


Fig.4. Khajurāho. Viśvanātha temple (AD 1002).

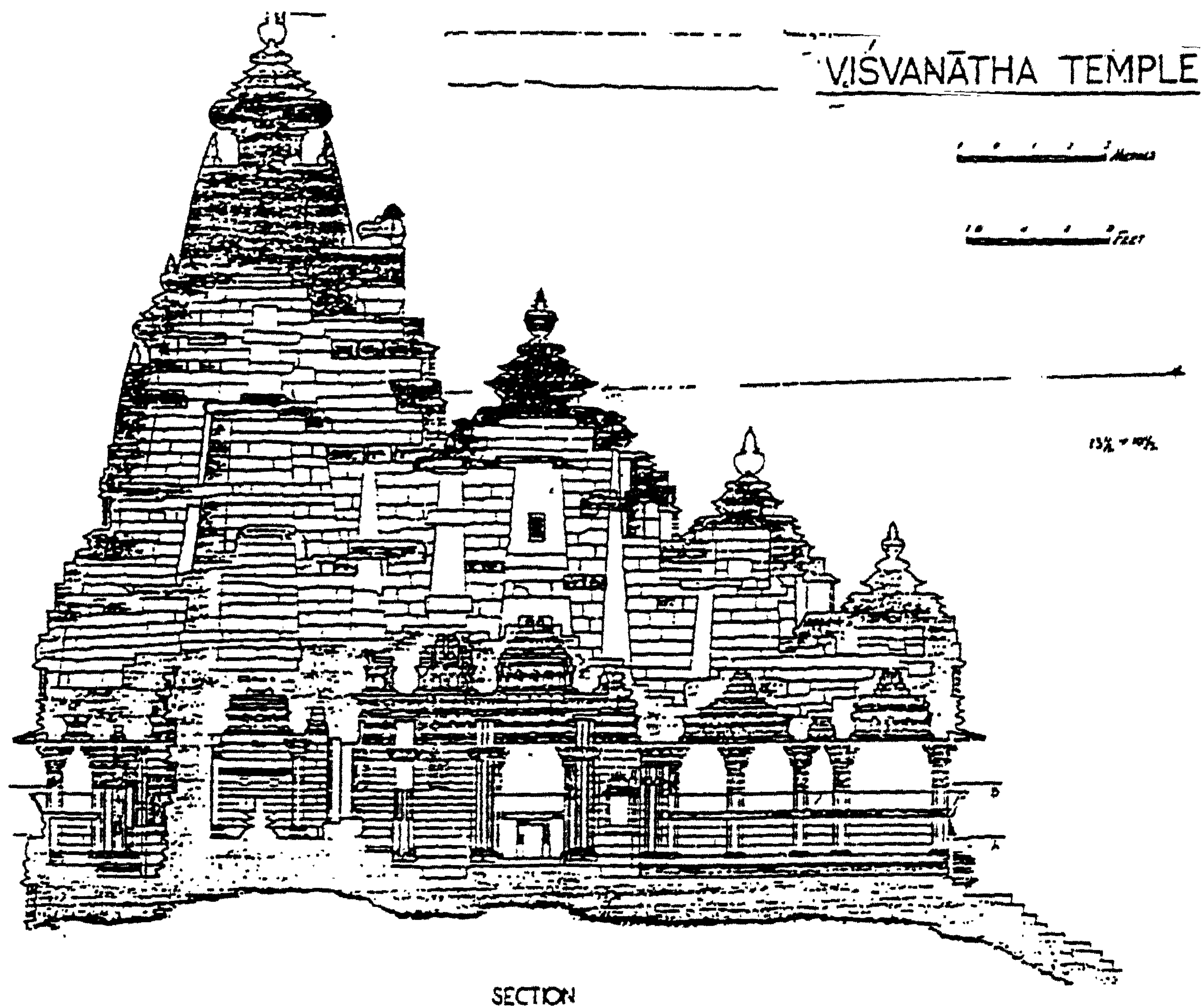


Fig.5. Khajurāho. Viśvanātha temple,Section.(Cāndelā style,AD 1001)

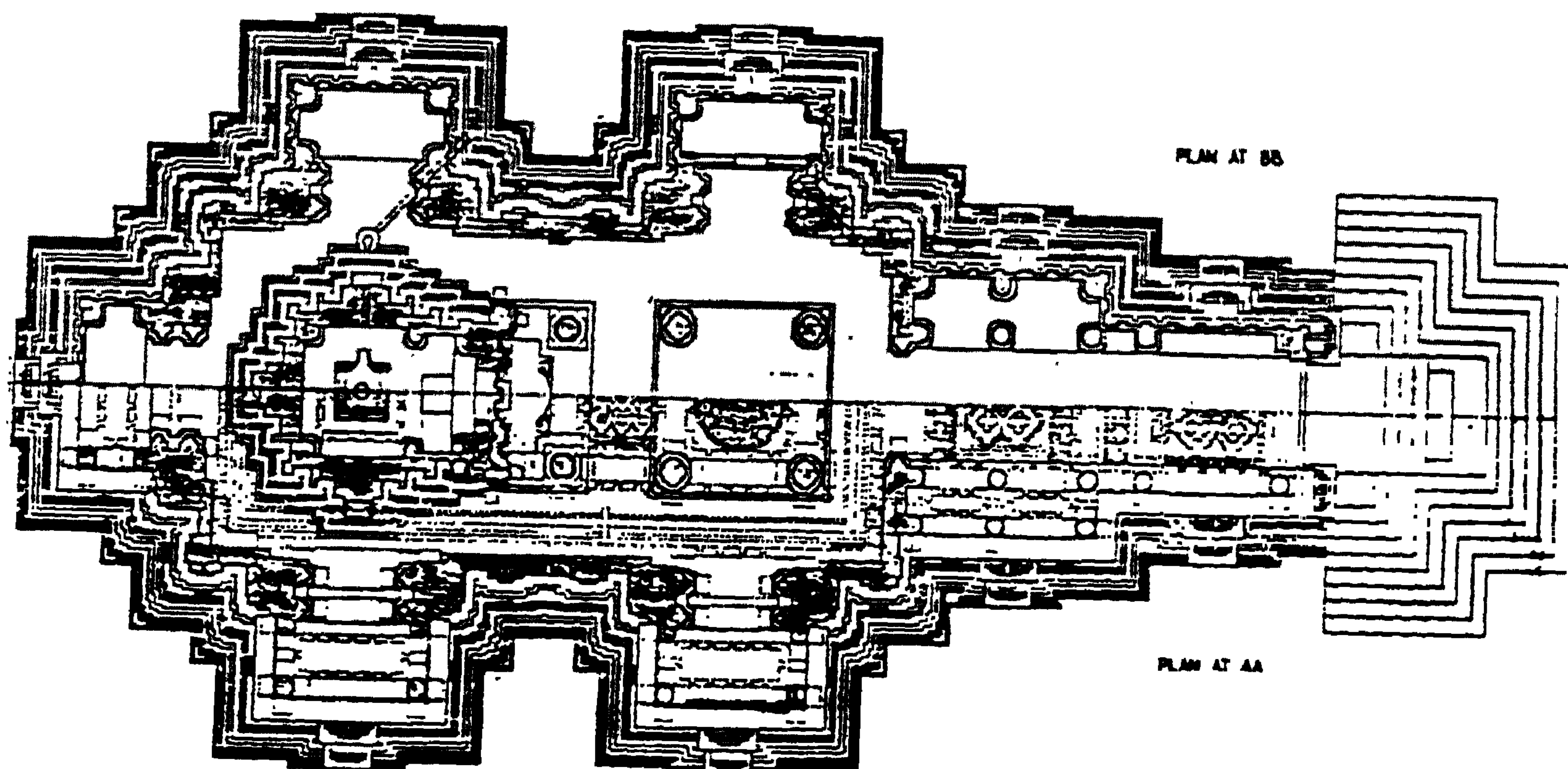


Fig.6. Khajurāho. Viśvanātha temple, Plan.

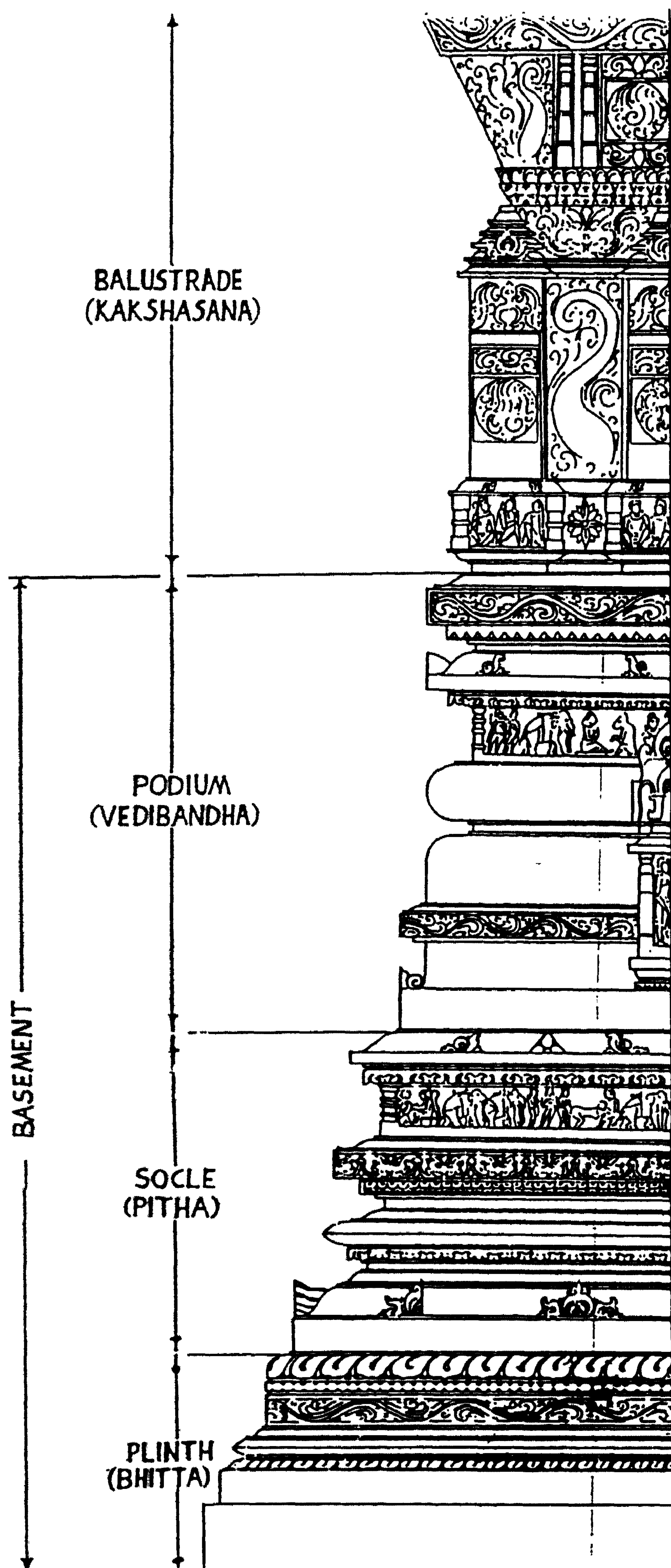


Fig.7. Khajurāho. Viśvanātha temple, māṇḍovara.

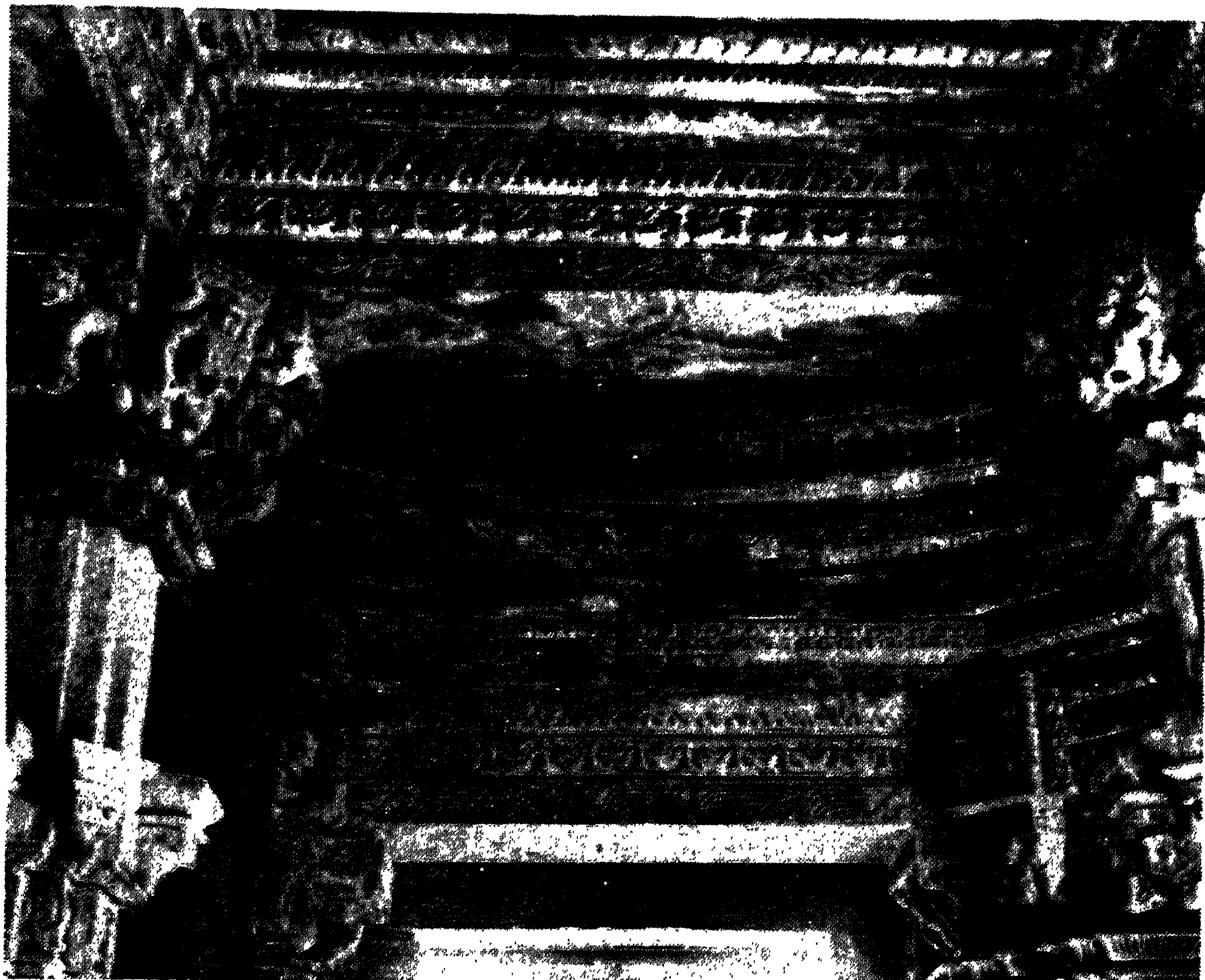


Fig.8. Khajurāho. Citragupta temple, maṇḍapa ceiling (c. AD 1025)

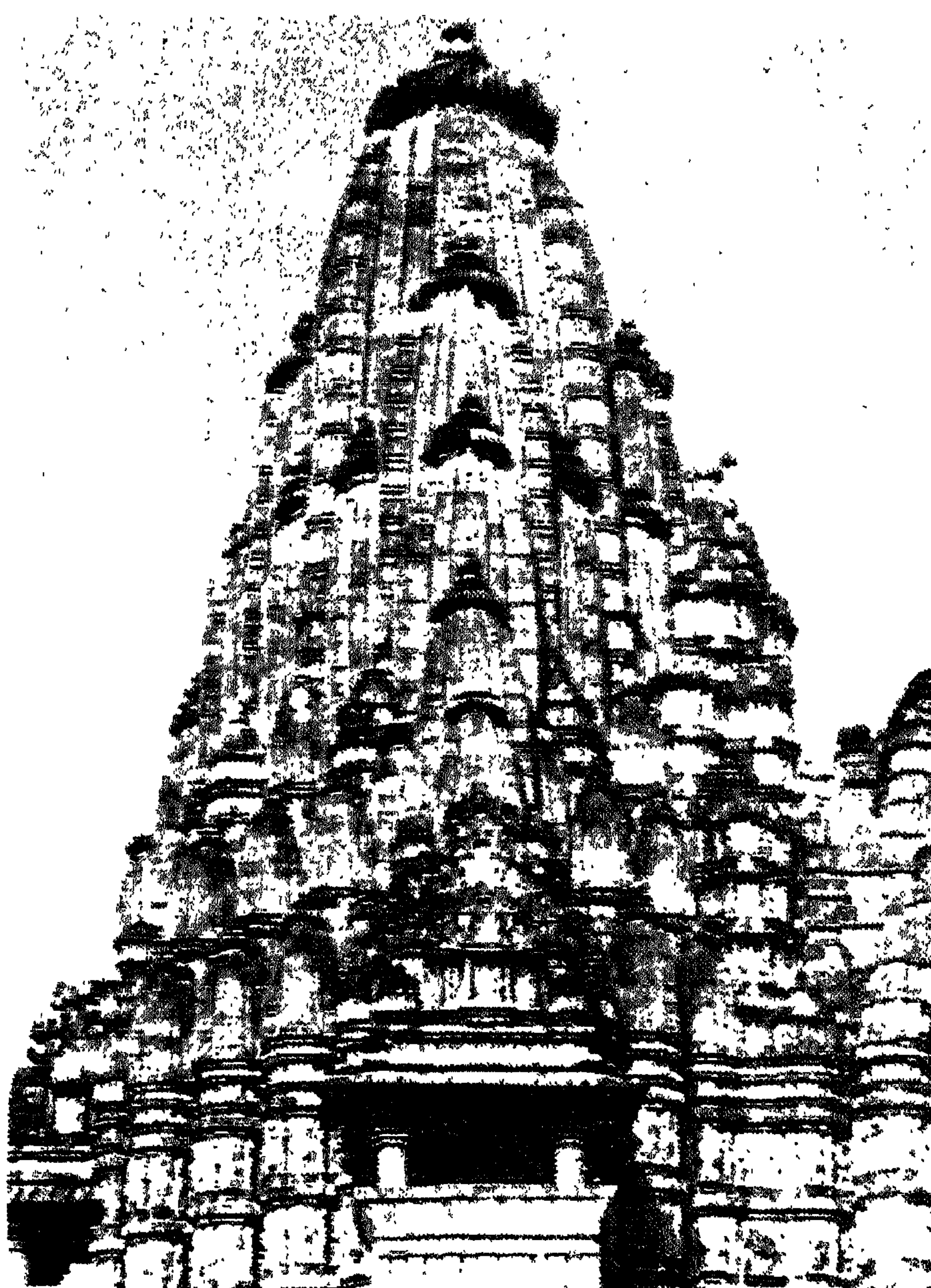


Fig.9. Khajurāho. Kaṇḍarīya Mahādeva temple, śikhara (c. AD 1040).

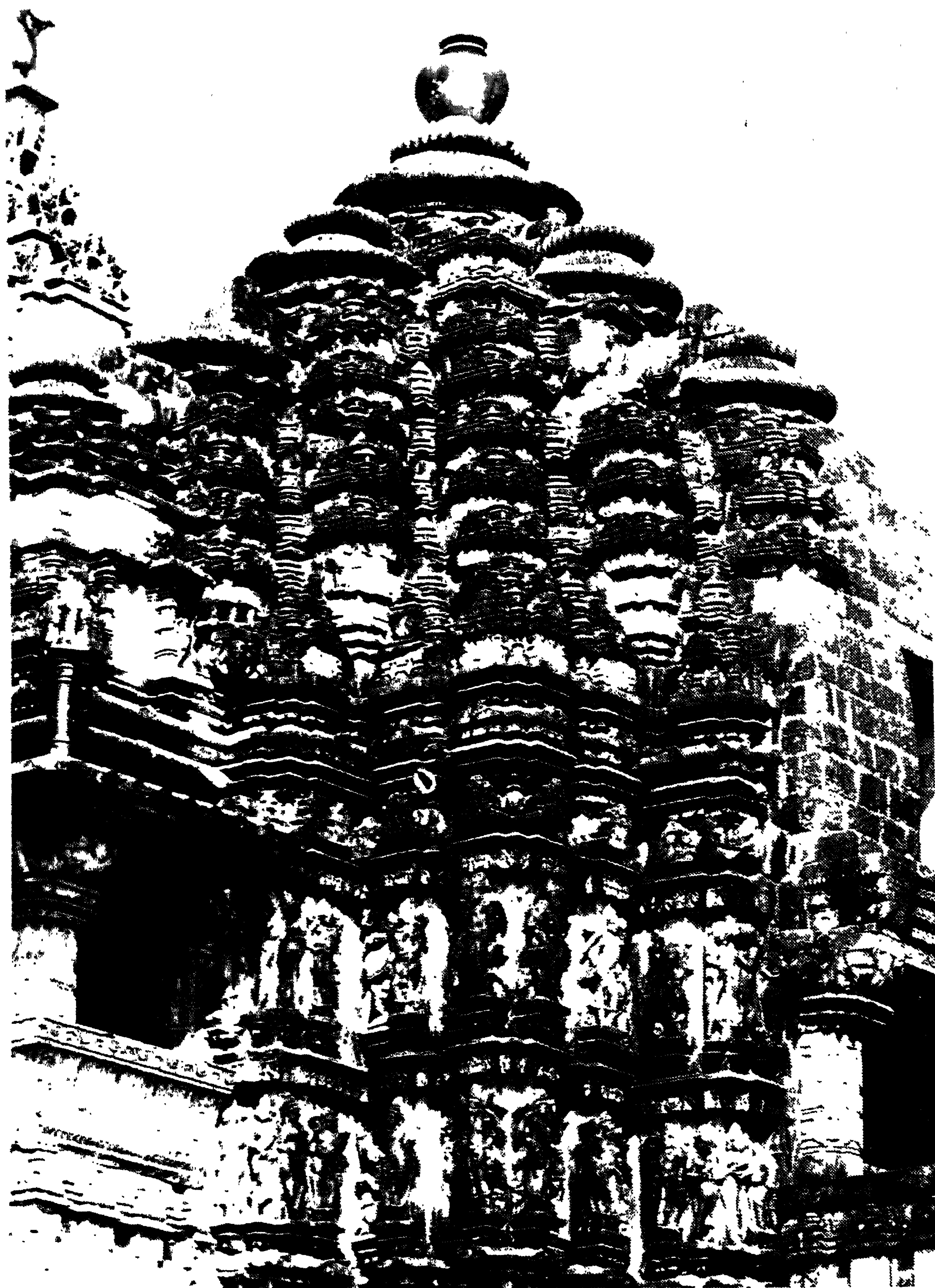


Fig. 10. Khajuraho. Vāmana temple, Saṃvaraṇā roof on maṇḍapa (c. AD 1060).

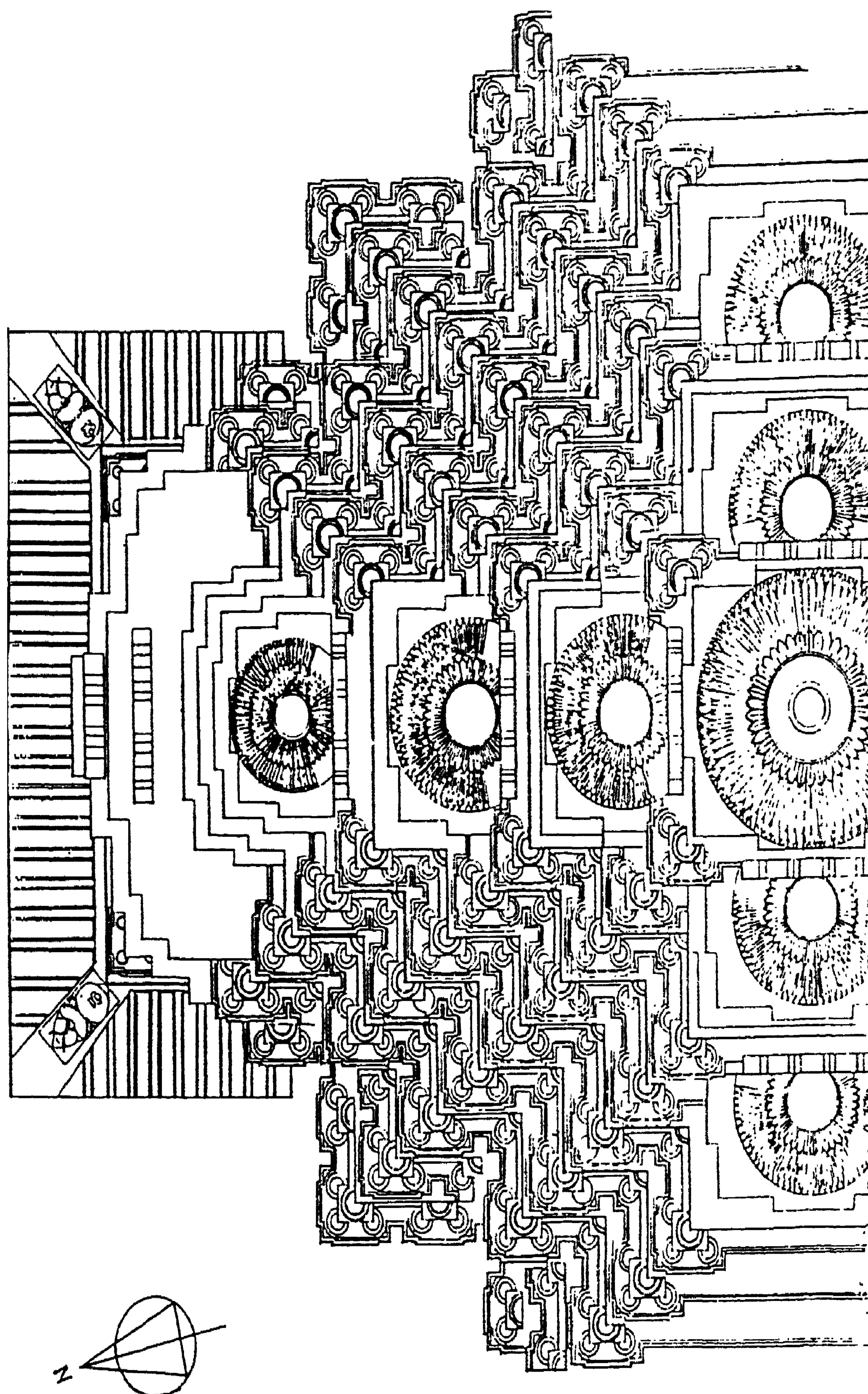


Fig.11. Khajurāho, Vāmana temple, Samvarana roof on maṇḍapa, plan (c AD 1060).

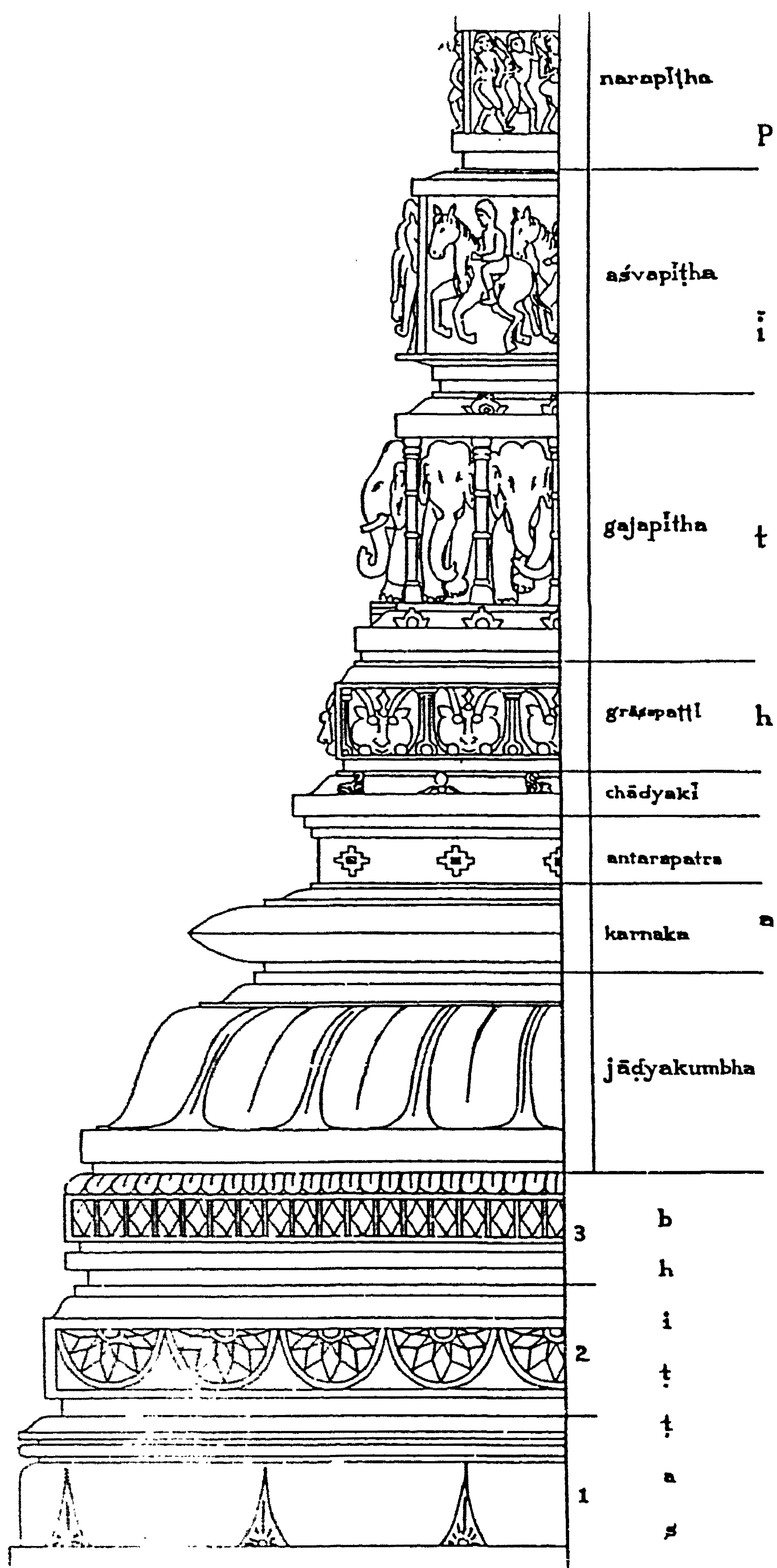


Fig.12. Pi [illegible] e. (Early 11th century, Courtesy: M.A. Dhaky)

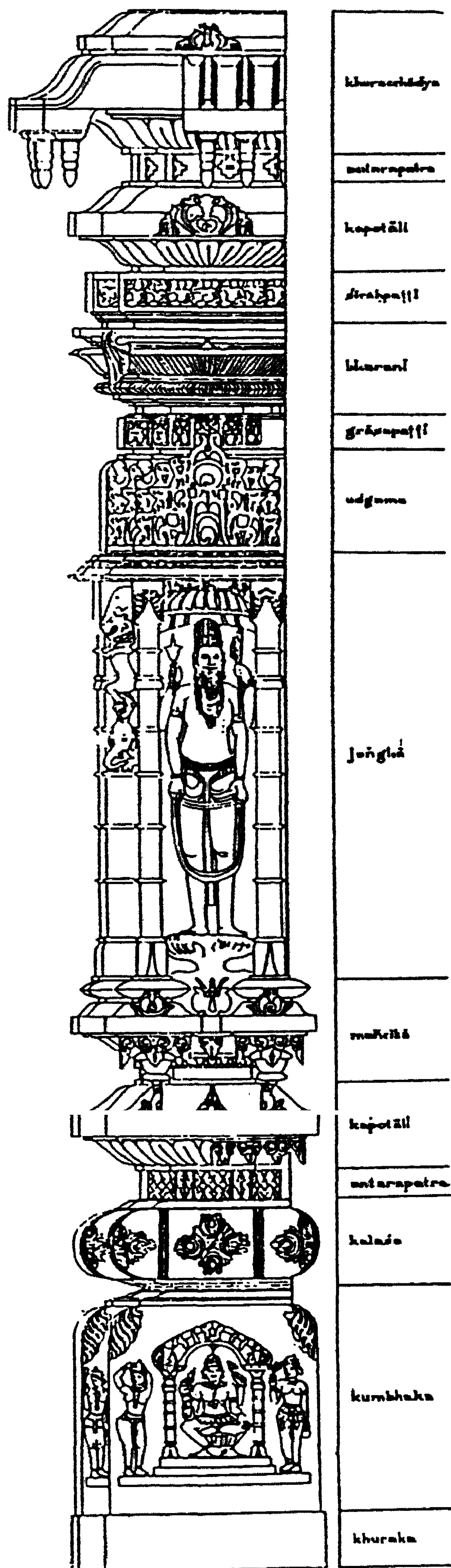


Fig.13. Maṇḍovara of Solankī temple. (Early 11th century, Courtesy: M.A. Dhaky)

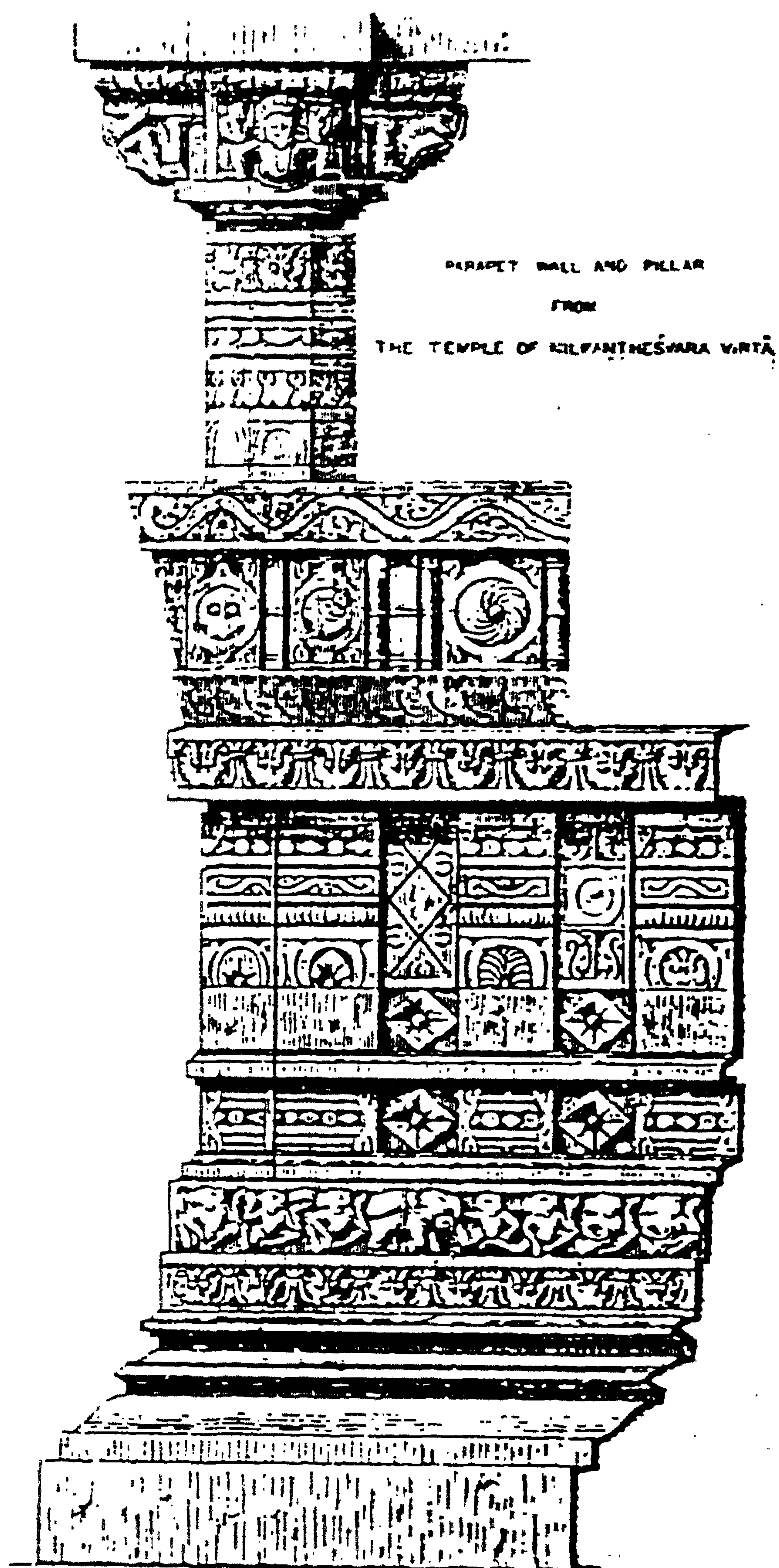


Fig. 14A. Socle, Kakṣāsana & pillar of Nīlakaṇṭheśvara temple, Virta. (Solankī style, 11th century)

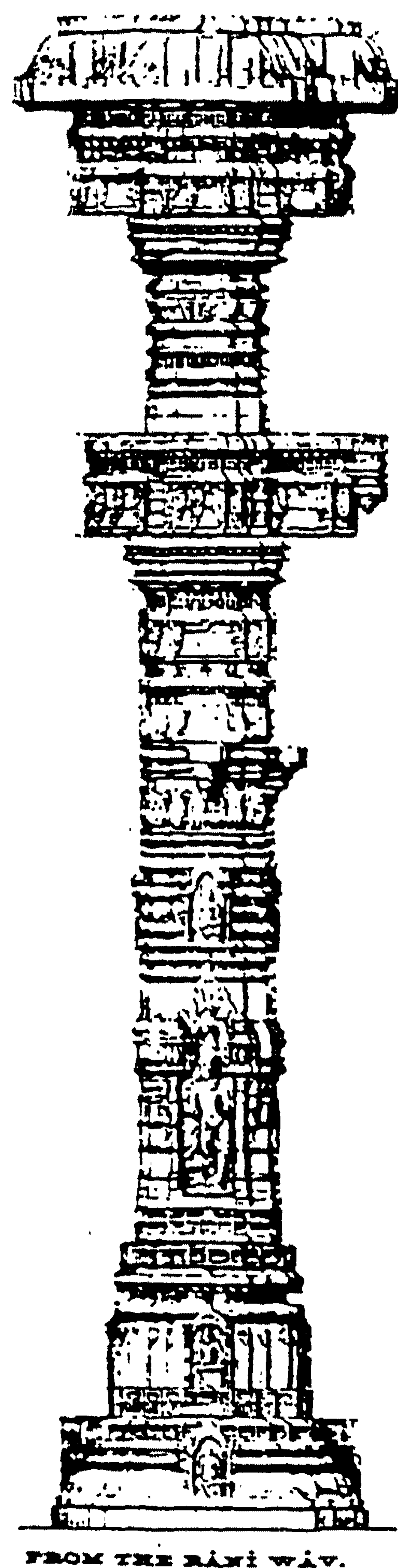


Fig. 14B. Pillar of Rāni Vav, Patan. (Solankī style, 11th century)

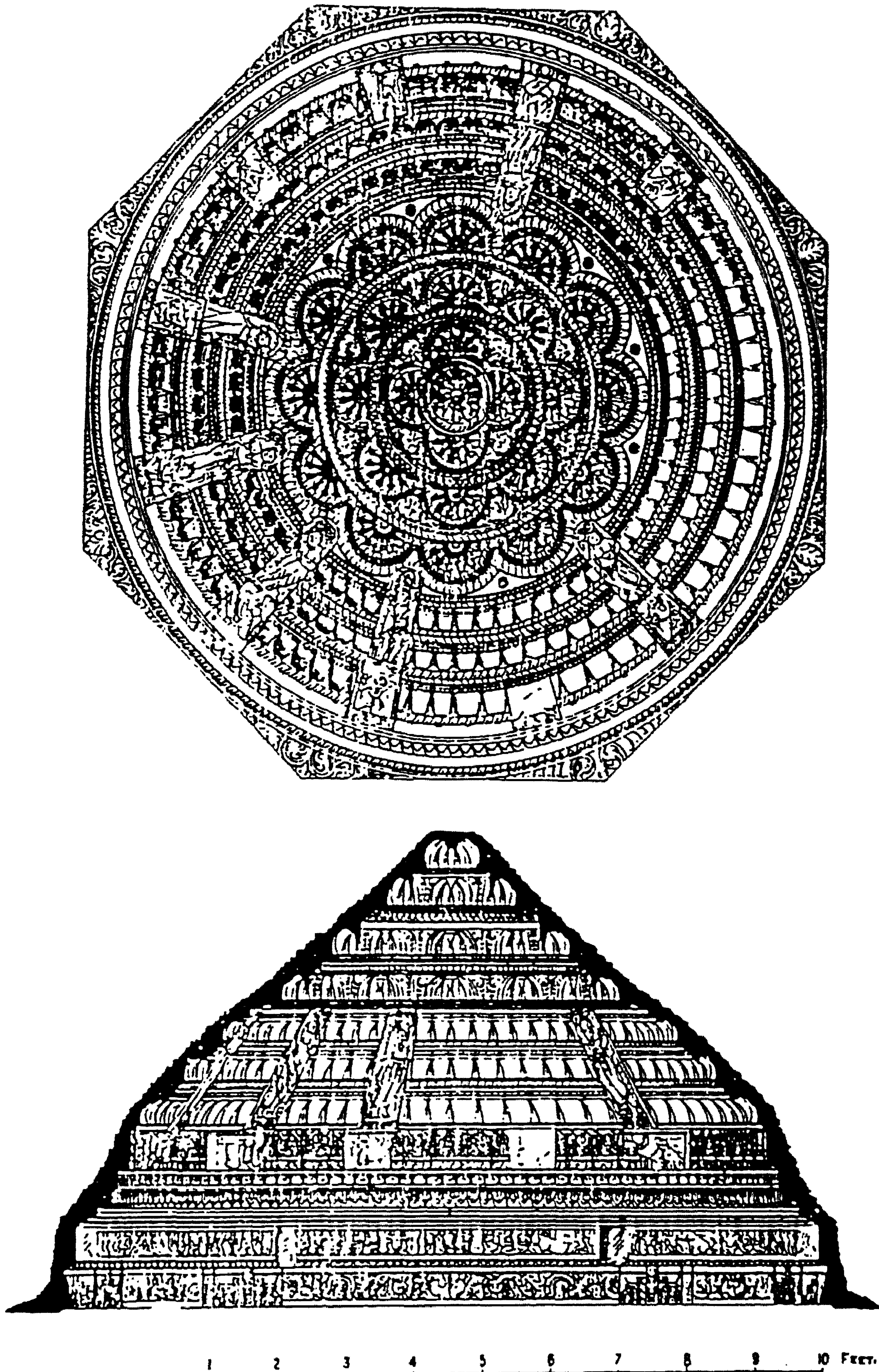


Fig.15. Maṇḍapa ceiling of Nīlakaṇṭha Mahādeva temple, Sunak.
(Solankī style, 11th century)

jāḍyakumbha(inverted cyma recta), *karṇikā* (knife-edge astragal), and *grāsapaṭṭi* (chain of *kirttimukhas*) are present in all schools. On ornate temples of the Solankī style of Gujarat these are surmounted by friezes of elephants (*gajathara*), and humans (*narathara*); sometimes intervened by a frieze of horses (*aśvathara*).

The Solankī temples also display a fixed set of mouldings and ornaments including the *vedibandha* and the main row of sculptures on the *jaṅghā* (wall) reaching upto the level of the *chādya* (awning) above which rises the *śikhara*.

According to *Aparājita* the śikhara should be 2 to $2^1/_2$ times higher than the *maṇḍovara* which includes the entire lower part of the temple upto the *chadya* (awning).

The curvature of *śikhara* is devised in *Aparājita* by two methods, viz. *Candrakalā rekhā* and *Udayakalā rekhā*. According to Candrakalā method the *rekhā*(profile of the *śikhara*) has 16 *khaṇḍas*. Each *khaṇḍa* is horizontally divided into 16 *kalās* and vertically into 16 *chāras*; the number of resultant *rekhās* thus total 16 x 16 = 256 varieties with a name for each. The Udayakalā system produces 435 varieties of *rekhās* by an alternate reckoning. That these variations are not exaggerated is proved by the divergent *śikhara* profiles in different regions of India and also by sample tests undertaken of the profiles of a number of temples in the same region. It will indeed be readily seen that the *śikhara* of a developed Orissan temple is distinguished by an almost straight profile terminating in a sudden parabolic curve at the top.

Some medieval temples of Western India had a complex type of *śikhara*, clustered by a number of *aṅgaśikharas* (subsidiary spires) whose minimum number was four and which increased by a successive addition of four numbers. The *Samarāṅgana-sūtradhāra* and the *Aparājita* describe a variety of Meru edifice with a hundred subsidiary spires while the former text discusses a variety with as many as 256 subsidiary spires.

Theoretically this number could go upto 1008, though actual example is available with just 84 subsidiary spires at the grandest temple at Khajuraho viz. the Kandariyā Mahādeva temple.

As regards the *śukanāsa* (antefix of the *śikhara* fronton) crowning the roof of the *kapilī* (vestibule between the sanctum and the *maṇḍapa*) the *Aparājita* enjoins that it is not to exceed in height the bell-member crowning the *maṇḍapa* roof. If the height of *śikhara* be 21 parts, that of *śukanasa* varies between 9 and 13 parts. Again the prescribed ratio of width between the sanctum and the *kapilī* (vestibule) should be $1{:}^1/_2$ or $1{:}^1/_3$.

The *Ksīrārṇava*, a Śilpa-text from Gujarat of the 15th century provides seven variations between 1:1 to $1{:}2^1/_2$ for the relative width of sanctum to *mandapa*. The *Aparājita* enjoins 27 types of *maṇḍapas* with pillars ranging between 12 to 64 through successive addition of two pillars, while another classification has 16 types of *maṇḍapas* by varying arrangement of bays. The same text also lays down 12 forms of a porch variety called *trika* (porch sandwiched between sanctum and *maṇḍapa*) and at least 5 types of festive or dance halls anciently known as *sabhamaṇḍapa* or *raṅgamaṇḍapa*. As regards the relative width of the *mukhāmaṇḍapa* (porch) and the *maṇḍapa*, the earlier ratio was 1:2 and the later one after the 11th century was generally 1:3.

The medieval temples of Western India had a special type of *maṇḍapa* roof called *samvaraṇā* which consisted of an orderly arrangement of diagonal rooflets crowned by cupolas consisting of bell members meeting a large crowning bell-shaped cupola.

The simplest had five cupolas including the crowning one, the second one nine and so on; with the addition of four cupolas in each successive variety 25 types were produced, the largest adorned with 101 cupolas. Such roofs also spread to Malwa and other parts of Central India including Khajuraho and Gwalior.

As regards pillar, the South Indian text *Mayamata* lays down that its diameter may be 1/8 to 1/10 of its height but for a ground floor pillar of a 12 storey high edifice the diameter should be 1/6 of the height. A pillar may be square, circular, hexagonal, octagonal or sixteen-sided in section or a mixture of the above with various types of capital, abacus and bracket conforming to specified ratios. On some North Indian sites like Khajuraho the central pillars of a *maṇḍapa* also had attic sections. Most pillars in North India had a broad base adorned with mouldings similar to *vedibandha* or *adhiṣṭhāna*. As a rule the pillars of Solankī and Paramāra styles had mixed square, octagonal and circular sections, all laden with zones of figural and decorative ornaments representing gods, nymphs, demigods, *kīrtimukhas*, etc. The ornamentation is also carried on the capital and bracket that support the beam, architrave and ceiling.

The developed Candela temples at Khajuraho, like those of other medieval Indian styles, had fixed and almost uniform elevational proportions. Thus, each temple was erected on an elevated platform (10 to 12 ft.) which was almost equal in height to the *adhiṣṭhāna* comprising *upapīṭha* (an optional member), *pīṭha* and *vedibandha*.

Again the *jaṅghā* (wall) upto the waist level approximated in proportion to the *adhiṣṭhāna*. The main *śikhara* (height 60 to 100 ft. above the platform terrace) was 2 to 3 times the height of the *maṇḍovara*, comprising *adhiṣṭhāna* and *jaṅghā*. The sanctum (8 to 11 ft. square), which was practically cubical, was three times the width of its doorway, while the height of the doorway was twice its own width. Each part of the edifice and its sub-part down to the minutest moulding had certain set measures and proportions which were fixed either canonically or traditionally. It will thus be seen that the Indian architect had a clear concept of well-tested, standard ratios and proportions and he built his grand edifice confidently, conforming to these.

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Irrigation and Irrigation Works

T.M. SRINIVASAN

Historical Background

Irrigation is the artificial application or method of supplying water to crops in countries where the rainfall is insufficient or comes in the wrong season. There are two types of irrigation, natural and artificial. The former is obtained through rivers, lakes, springs and rainfall and the latter type is by human effort in the form of excavated tanks, lakes, pools, wells, dams, embarkments, etc. These two systems of irrigation were in vogue in India from the earliest times. The pre-historic food-gatherers of India turned out to be "International producers" in the Neolithic age itself (Krishnaswami, 1959, p.1).

That the inhabitants of the Indus Valley riparian culture that had sprung and vanished at Mohenjo-daro and Harappa practised agriculture as the main industry is amply evidenced by the existence of food grains like wheat, barley, seasame, peas, etc. The cultivation of such food stuffs was made possible with the help of fertile alluvial soil, rather a heavy monsoon and the perennial waters of the Indus. They cultivated the winter crops such as wheat and barley with a system of irrigation. Raikes admits on the basis of hydrological studies that "winter irrigation requires the construction of barrages and large canals" (Raikes, 1984, pp. 455-60).

The pre-historic sites explored by the Indo-French Mission recently in Rajasthan desert displayed "a distribution pattern showing that they were certainly located along with branches of irrigation canals as they were in lines not necessarily following the Palaco-channel of Chautang (river Dṛṣāvati)" (IAR, 1986, p. 97). Moreover, the method adopted by the Harappans was seasonal damming of the rivers on the smaller branches. These barrier dams would have inundated the lands thereby depositing the fertile silt on the smaller river banks. The soil was cleverly extracted and utilised by them for their soil requirements. This barrier-dam irrigation system was subsequently destroyed by the invaders (Kosambi, 1975, p. 75). This is well documented in a number of hymns addressed to Indra in the *Rgveda*. Hence, the technique of flood-irrigation was known to them. The pottery speciments with deep grooves found at Mohenjo-daro suggest the possibility of

their being lashed to a wheel for raising water for irrigation. The discovery of a large number of wells at the same place shows that water was mainly derived from them for domestic and other purposes.

In the Vedic period water was given the utmost importance. The *Ṛgveda* (VII. 49.2) recognises four main sources of water, viz., waters which come from the sky or rain-water; those which flow in rivers and streams; those which are obtained by digging and those which ooze out from springs. Similarly, the *Yajurveda* (XXII. 25) identifies different types of waters from diverse sources. This amply implies that the vedic farmers were aware of and practised two types of irrigation, natural and artificial.

The method of collecting water from rivers and catchment areas in the hilly tract and carrying it through canals (*kulyā*) to distant areas was known to them. Moreover, they sought to supplement the rainfall and canal waters by digging wells (*avaṭa*). Water-lifting devices such as *aśma-cakra* and *ghaṭa-yantra* were made use of for lifting water from deep and large wells.

In the pre-Mauryan period, irrigation from rivers and canals were practised as before. Construction of irrigation works was considered to be an act of religious and social duty. In the *Sabhāparva* (Section V) of the *Mahābhārata* (Roy, p. 14), we find Nārada asking Yudhisthira thus: "Are large tanks and lakes constructed all over thy kingdom at proper distances, without agriculture being in thy realm entirely dependent on the showers of heaven? The interesting part of the Hāthigumpha inscription (*EI*, XX, No. 9, pp. 86-87) of Khāravela (1st cen. A.D.) is the extension at great cost of an ancient canal from the Tosali road. The canal was originally dug by king Nanda of Magadha who conquered Kalinga even before Aśoka and the Mauryans.

During the Mauryan period much importance was shown to agriculture and irrigation facilities by the State. Although there is only one instance of the State organised irrigation, the construction of a large reservoir, Sudarsana lake, by Puṣyagupta, (the governor of Candragupta) and later completed with a canal system by Tusapa, the Yavana governor of Aśoka it is clear from the *Indica* of Megasthenes and Kauṭilya's *Arthaśāstra* that the State recognised the importance of irrigation and encouraged private initiative in this direction. Perhaps this was done by the State to increase the State revenue.

In western India, the Kṣatrapa rulers continued the tradition of constructing tanks. In the second century A.D. the 'Sudarśana' lake suffered a breach (420 cubits long and 75 cubits deep) owing to heavy flood and on-rush of rivers Swarnarekha, Palasini, etc., and became 'durdarśaṇa' (*IA*, VII, 1878, pp. 259-61). It was restored and made more beautiful than ever (Sudarśanatara) during the reign of Rudradāman I under whose orders this work was carried out by the provisional governor, Suvisakha.

In the classical age and later, due recognition was given to irrigation, both natural and artificial. The *Amarakośa* (6th cent. A.D.) distinguishes between provinces watered by the rains (*deva mātṛka*) and those irrigated by the rivers (*nadī-mātṛka*). The *Nītisāra* of Kāmandaka (Maity, 1957, p. 83) advocates the importance of irrigation by human effort. Considering the importance attached to irrigation the

Gupta State evinced keen interest in the construction and restoration of irrigation work. Reference has been made to the Sudarsana lake. When the lake burst again as a result of heavy monsoon, Cakrapalita, who was the governor during the reign of Skandagupta, reconstructed it after two months' effort incurring huge amount of money.

In the extreme north of India, in the Kashmir Valley we read of Suyya, a great engineer - Minister in the service of King Anantavarman of Kashmir (9th century), who "made the streams of Indus and Jhelum flow according to his will, like a snake-charmer to his snakes" (Basham, 1954, p. 193).

In the southern region the practice of irrigation had its beginnings in the use of naturally formed small lakes and tanks by the Megalithic (Iron Age) people. The authors of Megaliths were settled people who practised agriculture as the main industry and knew the value and use of irrigation. It, may, therefore, be plausible to ascribe the authorship of the tank irrigation in the south to the megalithic folk (Banerjee, *ANI*, 12, p.21; Srinivasan and Banerjee, p.109). But in the historical period the absence of perennial rivers must have necessitated the rulers to resort to impound water for affording irrigation facilities for agricultural operations. Moreover, it is also largely with a view to removing the menace of years of failure of monsoons and the consequential drought that the irrigation systems of South India have been conceived.

Historical records prove that the organised irrigation system began in South India from the initial centuries of the first millennium A.D. This is quite evident from the early *Saṅgam* literary works. Tiruvalluvar in his *Tirukkural* (No. 737, *see* Pope (Eng. tr.) says the following as the important constituents of a kingdom: "Waters from rains and springs, a mountain here and water thence; these make a land with fortress sure defence". The *Puṟanāṉūru* (Srinivasa Iyengar, 1914, p. 43), a *Saṅgam* anthology, makes a pointed reference to the importance of "artificial tank irrigation" this: "Verily he who has turned the bent (low) land into a reservoir to arrest the flow of the running water is one who has established a name in the world". So the organised irrigation system in the South goes back to the Saṅgam age if not earlier.

The credit for launching large irrigation works goes to the early Cola king Karikāla (c. first century A.D.). The important achievement in his life time was the taming of the Kaveri by building the flood banks, cutting the inundation canals and strengthening the river embankments. This is testified by more than one inscription of the later period (EI, XI. No. 35, pp. 337-346; *SII*, III, pp. 249-50; *ASSI*, IV, p.217; *TRV*, III, pp. 154-155). In effect his pioneering activity successfully prevented the annual inundations for nearly fifteen centuries. Moreover, the lead given by him was followed by a number of other rulers who ruled the Tamil country in the succeeding centuries.

After the decline of the Mauryan Empire, the rule of the Satavahanas was followed in the Deccan who ruled for four and half centuries about 230 B.C. They were succeeded by the Ikṣvākus who ruled the Krishna-Guntur region from their capital from Nagarjuṇakonda. In the South West part of Deccan, the Kadambas of Vaijayanthi (Banavāśi) rose to power from the middle of the fourth century A.D.

Instances show that agriculture received the necessary patronage from the rulers during their regime.

The period from the seventh to the twelfth centuries A.D. witnessed the enormous growth and utilization of irrigation facilities provided by the early and later Pāṇḍyas of Madurai, the Pallavas of Kāñchi, the Colas of Tanjavur, the Hoysalas of Dwārasamudra, the Cālukyas of Kalyāṇi and the Kākaṭiyas of Warangal. This period was also characterised by the wider utilization of irrigation works and effective water management.

Records of the Pāṇḍyas point out that both the perennial and inundation channels from the river Vaigai were effectively utilised for irrigation purposes. Since the major part of the Pāṇḍya Kingdom was dependent upon the seasonal rains, only the rain-fed tanks were the next best possible choice for irrigation. More number of small scale reservoirs were constructed by the State and benevolent private individuals in the modern districts of Madurai and Rāmanāthapuram using the string-line technique for the embankments and stone-sluices (*karthūmbu*) (*SII.* XIV, No. 44). Even now one could find innumerable remains of ancient reservoirs in the above districts.

The Pallavas of Kāñci in the Toṇḍaimaṇḍalam region who ruled from the fourth century A.D. were great tank builders. From the available evidence we gather that irrigation was carried on with the help of tanks, inundation canals and channels and wells. The concentration of medium and small-scale tanks in the northern parts of Tamil Nadu (Chingleput and North Arcot districts, popularly known as 'Tank Districts') shows that the rivers Pālār and Vegavati were not only non-perennial, as they are today, but carried insufficient water to meet the irrigation needs of the cultivators. Some of the tanks constructed by the Pallavas continue even to this day to serve the purpose for which they were intended to. Canals were dug from the river Pālār to feed the small tanks which in turn were the main source of water supply to the fields by means of branch channels. The most notable works of the period are the Mahendra *taṭāka* (North Arcot) and the Citramegha *taṭāka* (Chingleput district) by Mahendravarman I, the Parameśvara *taṭāka* (Chingleput) by Parameśvaravarman, the Tirayaneri (8th cen. A.D., Cingleput), Kaveripakkam tank (North Arcot) by Nandivarman III, the Vairamegha *taṭāka* at Uttirameru (chingleput) by Dantivarman, and the tanks at Ukkal, Guḍimallam and Śolapuram (North Arcot) by Kampavarman. One important feature noticed in the Pallava records is that most of the projects were initiated and funded by the State. Private individuals were encouraged to construct works of irrigation. However, the maintenance part of it was entrusted to the village assembly; the assembly in turn received donations and endowments in cash and kind from the donees and invested the revenue part of them for the purpose of maintenance.

Following the Deccan tradition rural development was not neglected by the Rāṣtrakūṭas of Malkhed. The State was directly responsible for the construction of irrigation works largely for religious purpose. After the decline of the Rāṣtrakūṭas by the last quarter of the tenth century, the Cālukyas of Kalyāṇi rose to power. Unlike their counterparts in the Tamil country, the Cālukyans were not credited with the construction of many irrigation works. Recent excavations remains show that a channel about 300 feet in length connected the lake Sahaśraliṅga dug by

Sidharāja with the river Sarasvati, which evidently provided the lake with abundant supply of water (MurariKrishna, pp.194-195). Another important interconnected tank 'Big Tank' at Kāṭṭageri (Bādāmī tāluk) during the time of Vikramāditya VI is known from a Kannada record (*IA*, *VI*, 1877, No. xxxii). The tank is unique in the sense that the method of draining the excess water from a tank at a higher level to the tank at the lower level was successfully applied in this case. The Calukyans had a separate department of water works called *Vāri-gṛha-karaṇa* which was responsible for the execution and maintenance of irrigation works. The *Mahājanas* were responsible for collecting taxes and land revenue and utilising the same for the proper maintenance of irrigation works. The tradition set by the early Cola King Karikāla was assiduously followed by the Imperial Colas. This is well confirmed by a network of canals and branch channels from the Kaveri, besides a number of reservoirs of immense size. Canals and branch channels were dug from the Kaveri to cover the entire Kaveri delta. With the expansion of the Cola empire, the irrigation activities also increased manifold under the State patronage. In the absence of natural streams, recourse was preferred to tanks, and the bulk of the evidence on irrigation from the inscriptions relates to the care bestowed on the proper maintenance of the tanks. The agency responsible for the maintenance work was the village assembly. It consisted of several committees, of which the committee for the "Supervision of tanks" (*ēri-vāriyam*) was one. This body consisted of six members who held office for 360 days and then retired. The famous Uttiramerur inscriptions (*ANRIE*, Nos. 83 & 84 of 1898; *ANRASI*, 1903-1904) (Cingleput district) of Parāntaka I give an elaborate description of the rules regarding the composition of this Committee. The *eri-vāriyam* was in the main concerned with raising of resources and their utilization for the maintenance of irrigation works. There was another committee called the 'Sluice Committee' (*Kaliṅgu Vāriyam*) under the village assembly.

The duties of this particular committee was to maintain and check the sluice gates from wanton damage and other natural causes. This committee existed only in a few village assembly segments. The village assemblies on their part collected various types of land taxes, dues and cesses. Apart from this, as many as thirty- two tax items connected with the water-rates found in the records of the Colas were ostensibly collected from the tenants and land owners as service charges for the maintenance of irrigation works.

The Cola vāridhi (North Arcot), the Vīraṇameri (South Arcot), the Naṅgavaram tank (Tirucirāppalli), the Kaliyaneri (Madurai) by Parāntaka I, the 'Big Tank' at Bāhur (Pondicherry), the Arikeśarimaṅgalam tank (Tirunelveli) by Rājarāja I, the Cola- gaṅgam (Tirucirappalli) by Rajendra I, the Sembarambākkam eri (Cingleput) by Rājarāja III are some of the leading examples of a large of number of irrigation works mentioned in the inscriptions. The Tiruvalangadu plates (*SII*, III, pp. 3, verse 24, p. 425) of Rajendra I (1012-1044 A.D.) refer to the large irrigation tank 'Colagangam' as the 'Liquid Pillar of Victory' ('*gaṅga-jalamayam jayasthambam*') and states that, "This lord constructed in his own domain as a pillar of victory (a tank) known by repute as Colagaṇgam which was composed of the waters of the Ganges". About the extant Sembarambākkam ēri excavated by Rājarāja III, C.S. Crole says that it is "one of the biggest irrigation tanks in the

Chingleput district whose vast expanse of water, when it is full, is an object of attraction to the people in the vicinity, not to mention its immense utility for the agriculturist" (Crole, 1879, p. 70). The Hoysalas of Dwarasamudra in Mysore (first quarters of the 11th century) were not lagging behind in creating irrigational facilities by the construction of rain-fed tanks and canals. These works were undertaken by them for religious purpose. But there is no positive proof of any scientific and systematic planning of tank construction and the inscriptions do not offer any technical details. However, it may be inferred that it involved in the cleaning of jungle, levelling of land and fixing of sluices (Kuppuswamy, 1975, p. 48). Channels were cut from the rivers to channelise water to arable lands. On the contrary the Kākatīyas of Warangal in the Telugu-speaking area of the east had made significant contribution in this direction. "They inherited a system which had been in use in the land from time immemorial" (Yazdani, 1964, p. 677). The Hanmakonda *Niroṣṭya-kāvya* inscription (*EI*, XXXVI, verse 21, p. 217) states that "in the country (Andhra deśa) are hundreds of tanks and thousands of rivulets, and they indeed appear to be the ocean and the consorts respectively". Lithic records, literary compositions and the remains of extant irrigation works of the period bear ample testimony to the care with which the irrigation facilities were provided by them. Among the Kākaṭīyas, Gaṇapatideva (A.D. 1199-1262) was the most prominent ruler who was responsible for the construction of several irrigation works in different parts of the Kingdom. Among them the Pākhal lake, about 30 miles north of Warangal and the Rāmappa lake, about 44 miles north-east of Warangal are outstanding and surviving examples. The Pākhal lake lies in the basins of the Krishna and the Munnari rivers. King of the Geological Survey of India writing on the lake observes, "It is a splendid sheet of water lying back in two arms on either side of a good big hill east-south-east of the band, while from these are long bays reaching up behind low ridges of outcropping Vindhyas" (Bilgram & Willmott, Vol. II, p. 706 i.). At present the combined drainage of the lake is 80 sq. miles of which 40 sq. miles are intercepted. The Ramappa lake is formed by a ring of hills on three sides with a colossal bund only on the northern side. This lake is now fed by four channels. The lead given by Ganapatideva was followed by his successors in the 13th century also. In addition to tank irrigation, well irrigation was practised and it was confined to individual parcels of land. During the Kākaṭīya period the information regarding the method of construction was scanty and so our knowledge in this respect is very poor. However, different methods must undoubtedly have been employed varying with the terrain and locality. This is attested by the existing tanks of the period.

From the above brief account it may be concluded that because of the foresightedness of the rulers in ancient India, the problems like the seasonal drought and consequent famine were checked and brought under manageable control. The solution to the above problems was found in the creation of adequate irrigation facilities and thereby bringing under the plough newly created areas and increasing the land revenue to the State exchequer. It is thus no wonder that the present irrigation system is the result of the work of orthodox ancient Indian rulers who gave their experience and expertise in no small measure in the form of large and more expensive irrigation projects in the entire length and breadth of India.

It may be pointed out that there may be similarities or dissimilarities in the techniques involved in the construction of irrigation works from one period to another or from on region to another. But it is the local needs, exigencies and human experience that ultimately decide the technique and the selection of material. So, there is no question of one period following and continuing the techniques of the other period especially in ancient India.

Irrigation Works

Epigraphy and literature refer to this systematized practice of irrigation works as *Pāthas-Śāstra*. In Sanskrit *Pāthas* stands for water; as Varuṇa, the Lord of the waters, had borne the name *Pāthas-pathi*, hydrology, which deals with water, was appositely termed *Pāthas-Śāstra* (Mac donell, 1924, p. 160). Although regular treatises on this subject are not presently available, mention of the construction of reservoirs, canals and sluices with day, date and year and the arrangements for the distribution of water therefrom can be gleamed from a large body of inscriptions, copper plate grants and to a certain extent from the literary works. Besides, the works on architecture, the *Viśvakarmā Vāstuśāstram*, also gives an account of the construction of reservoir and wells. It would, therefore, appear that a special treatise on the science of hydrology must have existed in ancient times.[1]

There were specialists in the construction and execution of irrigation works. The *Yajurveda* pays tributes with reference this: "Homage to him expert in constructing wells and water falls. Homage to him who knows how to construct canals and tanks (*Kulyāyaśca śarasyāyaśca*)" (*YV*. XVI. 37). The persons who possessed the knowledge of the science of water was known as *āpo adhyānvacāris* (*YV*. XX.22) in the Vedic period. Engineers specialised in the construction of irrigation works were called *Jala Śūtrada* (Hydraulic Engineers). We find references to them in the inscriptions mostly from South India. Similarly, there were water-diviners (*Kūpadarśakas*) in the south (*SII*, XII p.2) who were professional water-diviners eking out a living by private practice. It is believed that they might have been working as inspectors of wells in those days. The duties of the engineers were purely technical. They were perhaps employed in the department of waterworks (*vāri-gṛha-karaṇa*)[2]. It was a separate body under which many subordinate department functioned. The hydraulic engineers did not confine their attention to the building of dams, tanks, canals etc. but the maintenance and repairs of irrigation works were also attended to. So there seemed to remain a sharp distinction between the hydraulic engineers and water-diviners. In the earliest traditions of Kashmir recorded by Kalhana in his *Rājataraṅgiṇī* (Stein, p. 200), the construction of irrigation canals and other waterworks by the genius of engineer-minister under Avantivarman increased the prosperity of the valley. He regulated the river Vitasta by systematic arrangements for the construction of irrigation channels. For these the water of various hill streams was utilised as well as that of the main river. "After examining the different classes of land he procured a supply of water for the villages, which thus were no (longer) dependent only on the rainfall. After watering all village (lands), he took from (each) village (some) soil, ascertained by (observing) the time it took to dry up, the period within which irrigation would be required (for each soil, respectively). "He (then) arranged (accordingly) on a

permanent basis for the size and distribution of the water course for each village and by (using for irrigation) the Anūlā and other streams, embellished all regions with arí abundance of irrigated fields which were distinguished for excellent produce". In the south under the supervison of the Hoysala Ballala Kings the hydraulic engineers brought the waters of the Yagaci river which flowed through a valley ten miles away and divided by a range of hills from the Halebid valley by af channel to supply the capital with water and fill the neighbouring tanks (*IA*, 1, p.44). These two recorded instances show the role of the hydraulic engineers in the execution of irrigation was considered important in the past.

Dams

Dams are barriers, natural or artificial, to hold back flow of waters. They were in existence from time memorial. Such prehistoric dams, now called Gebr-band, are still to be found on many water-courses in the Western parts of the region. The pre- Aryan method of agriculture depended upon natural flood and flooding the lands on the banks of smaller rivers by means of seasonal dams without regular masonary to obtain the rich alluvial deposit of silt to be stirred by the barrow. These artificial barrier dams broken by Indra are mentioned in the *Ṛgveda* (2.15.8, *vide* Kosambi, 1975, pp. 74-75) in connection with the *Vṛtra* myth. Here the term *Vṛtra* stands for 'obstacle', 'barrage' and so on. Such artificial dams are mentioned in the *Ṛgveda* as '*rodhas*'. These mountainous dams had flood gates which are described as the soft belly of the mountain from which the waters flowed. The flood gates are mentioned as *bila*, *ūdha* or *dūra* (*ṚV*. 5.32.11, *vide* Shendge, 1990, p. 255).

The bridge-cum-dam are generally mentioned in Sanskrit literature as *Setu*. The word '*aṇai*' in Tamil denotes a dam which we find mentioned in Tamil literature and inscriptions. Hemadri in the *Dānakhaṇḍa* of his *Catur-varga-cintāmaṇi* quotes from *Devipurāṇa* which says "The measurements of a superior type of *Pālibandha* are given as 200 cubits by the specialists in their treatises" (Satya Srava, 1953, p.5). The term *Pālibandha* possibly denotes a dam or embankment. Another term *Vipāli* mentioned in the *Devipurāṇa* must be smaller in dimension or subsidiary to *Pāli*. So the system of damming the rivers was practised for the purpose of irrigation.

The *Kunāla Jātaka* (prior to 4th cent. B.C.) mentions a dispute between the Sākiya and the Koliya tribes for the distribution of water from the dam across the river Hohini (Cowell, p. 19; Gupta, 1933). The earliest known reservoir with a dam is the famous 'Sudarṣana' lake in Kathiawar (c. 300 B.C. - 457 A.D.) (*EI*, VIII, No. 6, p. 46). This lake was formed by a natural dam and furnished with well-provided conduits and drains. An important fact about this reservoir-cum-dam is that it continued to serve the Saurashtra region for about 400 years without any major repairs. The masonary work must have been very strong. However, the lake suffered heavy damage by a storm during the region of Rudrādaman I in 150 A.D. The restoration work was carried out by his governor. After a gap of 300 years the lake again burst out during the reign of Gupta Skandagupta whose governor carried out the repairs and restoration of the embankment in 456 A.D.

In a late Tamil literary work, *Cola-maṇḍala Śatakam* (verse 28) we find a reference to the construction of a great dam known as *Kal-Aṇai* or the *Grand*

Anaicut across the river Kaveri (Nilakantha Sastri, 1932, p. 36). This anicut was not made of earth but of brick and stone. These is no conclusive proof to ascribe the still existing '*Grand Anicut*' to the early Cola king Karikalan. So the speculation is still rife as to the ruler who was responsible for this great work. Probably the greatest achievement of ancients in executing a large dam-cum-reservoir was the Bhojapur lake near Bhopal built in the 11th century by Bhoja Paramāra (died A.D. 1055-56), the King of Dhārā. This lake was created by carefully erected dams of moderate size and covering an extensive area of 250 square miles. They consisted of an "earthern central band faced on both sides, outer and inner, with immense blocks of stone laid one on the other without mortar, but fitting so truly as to be watertight, the two faces sloping inwards from the base. The lesser opening (barrage) was closed by a band 87 feet in height, and 300 feet thick at the base, or even more the greater (barrage), by one in places 40 feet high, and about 100 feet broad on the top; and, though the first mentioned band is now a complete wreck, the latter is intact and still continues to turn the river Kaliasot into Betwa, and from its top the old bed of the stream is recognisable" (*IA*, XVII, p. 350ff). The lesser but higher barrage was breached by Shah Hussain (Hoshang Shah) in the 15th century, and has never been restored.

Reservoirs

Reservoirs are constructed to impound water to irrigate large tracts of arable land in the absence of rivers and dependable channels leading off from them. Usually a reservoir is surrounded on three sides by earthern embankments and the fourth side is open to the catchment area from which water flows down to collect in the basin of the reservoir. The water reaches the fields by gravity flow, below the embankments through openings or sluice gates or valves. The reservoirs which are fed by channels from rivers are known as "system tanks". These types of reservoirs were constructed mostly in the southern region to augment irrigation needs. The artificial reservoirs, usually referred to in Anglo-Indian jargon as 'tanks', were variously known as *śarasi* (Sanskrit), *ayam*, *eri*, *taṭāka*(Tamil), *samudra*, *sarovara* (Kannada) and so on. The reservoirs were named after the benefactors, royal dignitaries, rulers, dynasties, deities with the above mentioned names as suffixes. To indicate the variation in size and economic importance of tanks, *eri*, *samudra*, *sarovar* applied to very big water formations. Lesser formations, artificial or natural, were also designated by such names.

Much attention was paid to the proper location of tanks and dams. The *Mahābhārata* (Roy, Eng.Tr. II, p. 14) stresses that large tanks and lakes should be constructed at proper distances. Manu, the Law giver, advocates that dams, wells, tanks and *prasarvaṇas* should be built where boundaries meet (*MS*, VIII, 248; *vide also* Eng.Tr by Buhler). As their locations were vulnerable to attacks by the enemies the idea of locating them on the boundary lines was not advocated by Kauṭilya. He recommends that the tanks and dams should be constructed in the centre of a province or village (*AŚ*,III, 51, Shamasastry,1961). Tiruvalluvar in his *Tirukkuṛal*; 'Sacred Couplets' (22.5; *vide* Eng.tr. Pope, 1886) compares wealth in the hands of the liberal minded people to the water in the Central tank and this confirms that

tanks were located at the central place for all to benefit, such public tanks were known in Tamil *Ūruṇi-kuḷam* (drinking water pond for public).

The site selected for the construction of large reservoirs by the tank builders was in between two mountains; for the mountain slopes on either side served as the natural embankment. This sort of arrangement undoubtedly increased the storage capacity of the reservoir. This technique is, of course, possible where there is such a natural arrangement. The famous Sudarsana lake in Kathiawar was located round the mountain Girnar. It was "so well joined in construction as to rival the spur of a mountain" (*EI*, VIII, No. 6, p. 46). The Ciramegha *taṭāka* constructed in the first quarter of the 7th century A.D. by the Pallava Mahendravarman is by far the largest tank in the Cingleput district, Tamil Nadu. It is situated in between two hills which form the natural embankment for it. "The bund rests upon the bases of two hills and lets rise here and there in the centre of the reservoir making it the prettiest tank in the district" (*Madras District Manuals: North Arcot*, II, p. 305). As already mentioned, the Bhojapur lake near Bhopal was created by constructing two solid masonary dams across the watershed of a circle of hills. The Rāmappa lake constructed during the reign of the Kākaṭīya Ganapatideva at a distance of 44 miles north-east of Warangal (Andhra Pradesh) is an excellent testimony to the skill of the Kākaṭīyas in irrigation works of a high order. This magnificent lake is formed by a ring of hills on three sides with a colossal bund (embankment) on the northern side (Gopal Reddy, p. 62). The same technique was applied by them in constructing a tank at Buddhapuri (Andhra Pradesh) (*CTI*, p. 52).

After selecting the site either in a hilly tract or in plains, the bed of the reservoir in the basin system was strengthened with hard clay. Further, the entire area enclosed by a group of hills or earthern embankments was adjusted to form the bed of the reservoir. The elevation (*kūrma*) in the middle of the tank bed was totally avoided. Otherwise, the storage capacity of the reservoir would be reduced. The bed of the reservoir at the egress was formed of stony bed along a tortuous line, so that the water issued from it whirled round with great force, forming strong eddies (*EI*, XIV, p. 108, f.n. 8). It was provided with an inlet and outlet channels and the inlet channel was normally three *yojanas* distant from its source. In the basin system it was also the practice to carry the flood waters into the basin by canals. Main canals carried the water from a river. Distribution canals fed the water from the main canals into the basin. A dam across the portions of hills was constructed of a firm and compact stone wall. The stones from the quarry were straight and long to withstand pressure and strain. In the mountainous tract the question of an earthern embankment strengthening it with stone facing did not arise; whereas in the level plain it was necessary to throw up earthern banks all around the tank bund.

Taṭākas were dug and built either in the middle or the peripheral area of the village. Care was always taken that in the site chosen there were springs of good drinkable water. A well was usually dug in the middle of the tank with its length in the north south direction. The tank was also fitted with an inlet and outlet channels for filling and emptying it (*Kalavali*, 2:4; *Nānmaṇikkaḍigai*, 73:3). Big tanks attached to temples were provided with a number of deep sunk wells (*uṛai-kiṇaru*) and *maṇḍapa* at the centre which was known in Tamil as *nīrāli maṇḍapa*. Such tanks were generally provided with flights of steps, a covered

verandāh or corridors or platform all round and ornamental gateways on all the four sides (*VV*. p. 51).

Although isolated tanks which were fed by the run off waters from their own catchment did exist, it was common to have tanks as part of an interconnected chain of tanks, wherein the surplus waters of one flowed down to the next tank down the line and so on. It would be of topical interest here to quote the rules laid down in the *Arthaśāstra*.

"The water of the lower tank, excavated later on, shall not irrigate the field (already) irrigated from the higher tank; and the natural flow of water from a higher to a lower tank shall not be stopped, unless the lower tank has ceased to be useful for three consecutive years" (*AS*. II. 9). The real significance of this injunction laid down by Kauṭilya is that there was such a system of carrying the surplus water of one tank to another in ancient times. We have two classic instances from the south. The Vīranārāyaṇa eri or Viranam tank (first half of the 10th century A.D.) is at the fag end of the Kaveri delta near Kattumannar Koil (South Arcot District) and 8 miles west of Gaṅgaikoṇḍasolapuram (Tirucirappalli district). The bund of the extant reservoir alone is 10 miles in length and has amean width of some 3 miles. "The circumference of the tank when it is full is nearly 25 miles" (GAAD, 1906, p. 132). The surplus water of the famous 'Colaganam' tank (now in ruined condition) constructed by the Cola Rajendra I in 1012-14 A.D. at Gaṅgaikoṇḍa-solapuram went to make up this tank through a canal. Another interesting instance comes from Karnataka. A Kannada inscription (*IA*, VI. No. 32, pp. 138 ff.) dated 1096-97 A.D. from Kāṭṭageri (Bādāmi Taluk, Katadgi district) refers to the existence of a 'Larger Big tank' during the rule of the Western Calukya ruler Vikramaditya VI. J.F. Fleet, who identified the place and the tank based on the inscription, attributes three reasons for the sustained water supply in that area after *in situ* inspection of the place. "The system of tanks at Kāṭṭageri was formerly a large one. First, there is the small tank, on the west of the Fort, and close under the walls ... Secondly, there is a larger tank, on a slightly higher level, which if repaired, would, when full, include the proceeding in itself, formed by an embankment running to the south from just below the south-east corner of the Fort. And thirdly, about 1/4 of a mile away to the south-east of the proceeding, and on a lower level there are the remains of a large embankment, now breached and quite useless, which when in repair, evidently formed a tank of considerable area". From the above description, it is discernible that the method of draining the surplus water from the tank at the higher level to the tank at the lower level must have been successfully applied in this case. These two instances prove that the ancients had a sound knowledge of hydraulic engineering while planning and executing the irrigation works.

Sluices

Sluices are contrivances in the form of gates or valves through which the flow of water can be controlled or stopped. They are also used for surplus vents. For better flow of water from the reservoir, the sluices are usually installed at points of maximum depth and quite far from the embankments. The sluices were not

unknown to the pre-Aryans who had barricaded the streams of seven rivers, *Sapta-Sindhavah* (*ṚV.* I. 51.4; VII 82.3). It is disappointing to note that the northern sources do not offer any tangible material in this connection. *Udagabandha* (Sanskrit), *madagu*, *kalingu*, *tūmbu* (Tamil), *tubu* (Kannada) and *tumus* (Telugu) are the terms generally met with in the inscriptions to denote a sluice (*EI*. III. No. 20; *Śilappadikāram*, X. 109; XII. 4.1; *ANRIE* No. 257, 1952; No. 552, 1902, *SII*, III, p. 392).

In the *Paripāḍal* (verse, 20, ll.90-107; *see also* Balakrishna Mudaliyar, 1960, p.38), one of the *Saṅgam* anthologies, we come across a passage in which it is mentioned that the river Vaigai near Madurai was then a mighty river, and to control and regulate it when in freshes,several water-heads and large underground sluice shutters were constructed for the purpose. So it is not a matter of coincidence that we notice in the early and later Pāṇḍya records from the 8th century onwards a good number of references to the construction of sluices to river channels and small-sized reservoirs in and around Madurai.

References to the installation and renovation of sluice gates are more in South Indian lithic records pertaining to the Pāṇḍyas, the Pallavas and the Colas. It is equally interesting to note that the tanks constructed in one period were provided with sluices in another period. But they add a little to our knowledge of the types of sluices used in the regulation of water.

Depending on the size and water-spread of the reservoir the number of sluices were determined. The Tirayaneri in the Cingleput district constructed in the first half of the 8th century A.D. by some predecessor of the Pallava Nandivarman II was provided with 23 sluices and stone revetment (Sewell,1882, p.188). The extant Viranam tank or Vīranārāyanppereri, a large reservoir, constructed by the Cola Parāntaka I (c. 950 A.D.) at the fag end of the Kaveri delta (South Arcot district, Tamil Nadu) has 74 sluices (*GAAD*, 1906, p. 132).

Similarly, the 'Colagaṅgam' reservoir constructed by the Cola Rajendra I was provided with several sluices and channels for the irrigation of a large area. During the period under review, the sluices were installed by the use of dressed granite slabs in place of laterite blocks; and some times the planks of palmyra trees joined together by means of ropes were also used as a make- shift arrangement (*ANRIE*, No. 417, 1912). A single evidence from Sirgāli (Tanjavur district, Tamil Nadu) records the exact measurement of a sluice (*ANRIE*, No. 499, 1918). It measured in modern conversion 35 inches in length and 8 inches in breadth. It is presumable that this sort of narrow sluice shutters were put to use to regulate the water-supply from the branch channels.

Head Sluice: The Head-sluice (*Kūṟṟan-vay*), as we understand from the Pallava records, is a sort of regulator. It is usually a strong masonary work at a point where the canal takes off from a river or tank; and its purpose here is to control the supply entering the canal. *Muka-vāy*, *talai-vāy*, *vāyt-talai* are the other terms in Tamil to be identified with the head-sluices (*SII*, I, 151; *EI*; V p. 49). Above the head-sluice was constructed a 'head of water' (*uvantri* or *taluippelai*) with a large mouth or opening which conveyed the excess flow of water entering the canal from the main sluice (*SII*, II. No. 93, p. 11; III, p. 530).

A remarkable piece of native engineering work, which is still in a fairly good condition supplying water to the town of Tiruchirappalli (Tamil Nadu) is the massive head-sluice (*Vāyttalai*) of the Uyyakondan channel, which branches off from the Kaveri near the Veṭṭuvāyttalai Railway Station. This head sluice is made of a solid granite block.

On the bridge which crosses the head-sluice is placed a stone, which is stated to have originally formed part of one of the pillars of the sluice itself. This head-sluice was constructed about A.D. 1205-06 for conducting water to flow into the Uyyakondan Channel during the reign of the Cola Kulottunga III (*ANRIE*, No. 70, 1890; 1891 para 4; *SII*, IV, no. 394, p. 119). Another example of such a nature comes from the same district. This head-sluice, now popularly known as *nāṭṭu-vāykkāl* (native channel) or *Periya-vāykkāl* (big channel), is on the northern bank of the Kaveri near Musiri (Tirucirappalli district). This head- sluice is spanned by a bridge across the channel *Periya-vāykkāl*. On one of the side walls of the sluice close to the bridge is an inscription of Rājarāja Cola III which records that in the fourth year of his reign (A.D. 1219), the head-sluice was built of stone at Musiri (*ANRIE*, No. 72, 1890; 1891, para 4; *SII*, IV. No. 396, p. 120).

The major part of the Pandya region in the South (Madurai and Rāmanāthapuram districts) depended on rain-fed servoirs for irrigation. They were carried out by the early Pāṇḍyas (7th and 8th centuries) and continued by the later Pāṇḍyas from the 9th century onwards. All the surviving reservoirs, mostly medium- sized, with stone sluices (*Karttūmbu*) of the period would indicate the technical skill involved in the construction of reservoir for irrigation. "The position and depth of the sluices demonstrate adequate knowledge in choosing the most suitable points and ascertaining the correct sill level" (Rajan, 1986, p. 159).

The following information regarding the working of the *tūmbu* sluices is based on in situ inspection of certain early sites by Rajan Gurukkal, since none of the *tūmbu* inscriptions is published (*Fig.1*). "The *tūmbu* was a single valve system operated without any devices for mechanical advantage. It consisted of two granite pillars installed in the reservoir on either side of the sluice-mouth. The pillars varied in height, according to the depth of the reservoirs. The distance between the two pillars was about one to one and a half meters. The pillars were connected to each other by a series of cross-slabs from the base of the sluice to the top. Each cross-slab had a hole in the centre with a diameter of about 5 to 8 inches. The base of the system was a rectangular enclosure built in granite on the bed of the reservoir. It had a rectangular opening of 1 ×2 feet. The stone above the opening had a long aperture and the stones on either side of the opening had slots, obviously for the movement of the shutter plank. It appears that, through the series of holes in the cross-slabs, a wooden rod lowered to the sluice-mouth. The edge of the rod must have been connected to a shutter-plank lowered through the long aperture so as to cover the opening of the sluice. The operation of the system was quite simple. The sluice-mouth could be opened by lifting the rod. The lifting of the rod was not difficult since a little opening would cause enough upward thrust from the flow of water for the shutter-plank to move easily. The sluice opened into an underground conduit which lead water to a well called *etirakkiṇaru* built outside the embankment. Unlike the ordinary wells, the *etirakkiṇaru* was constructed upwards

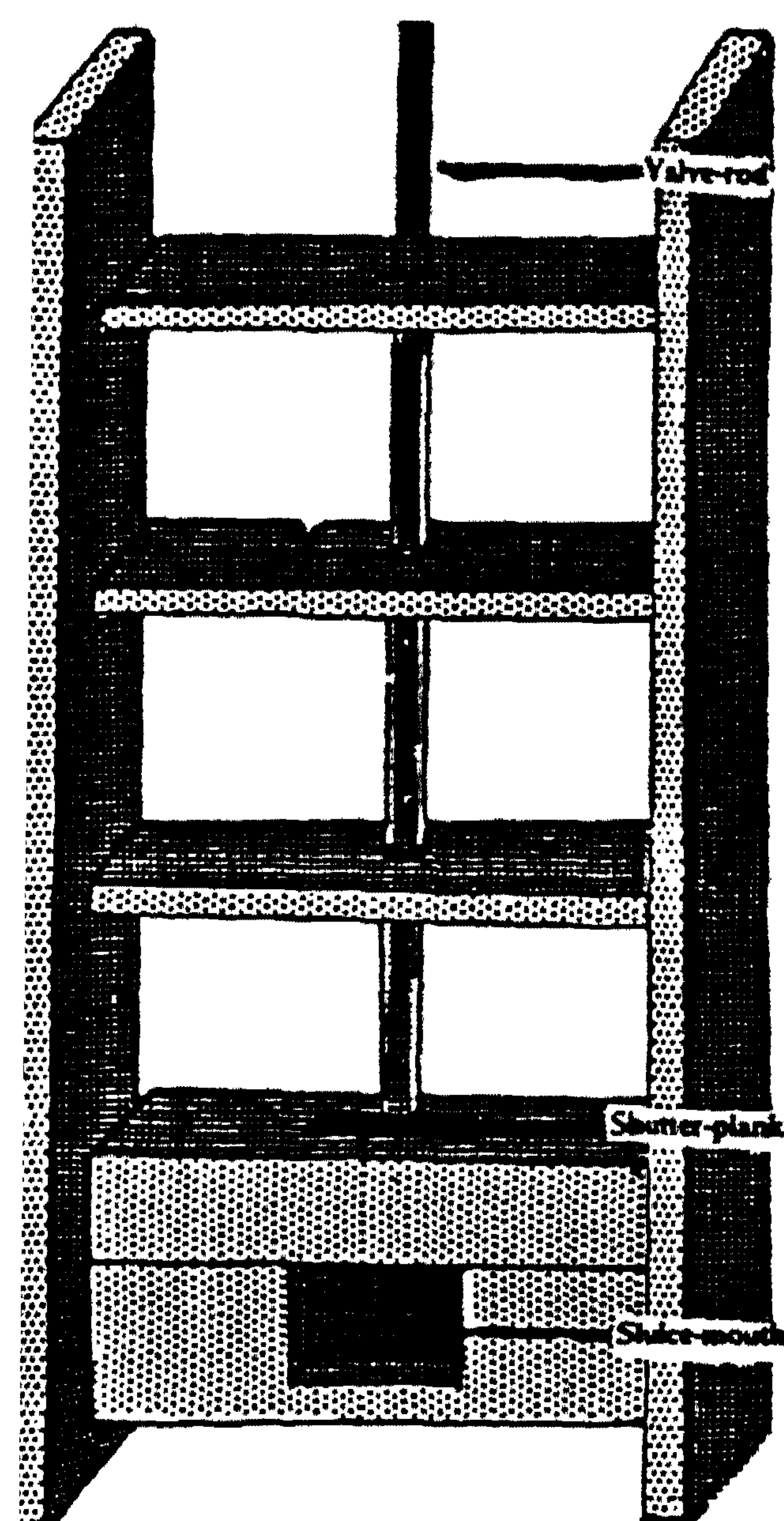


Fig.1. Tūmbu (sluice) system

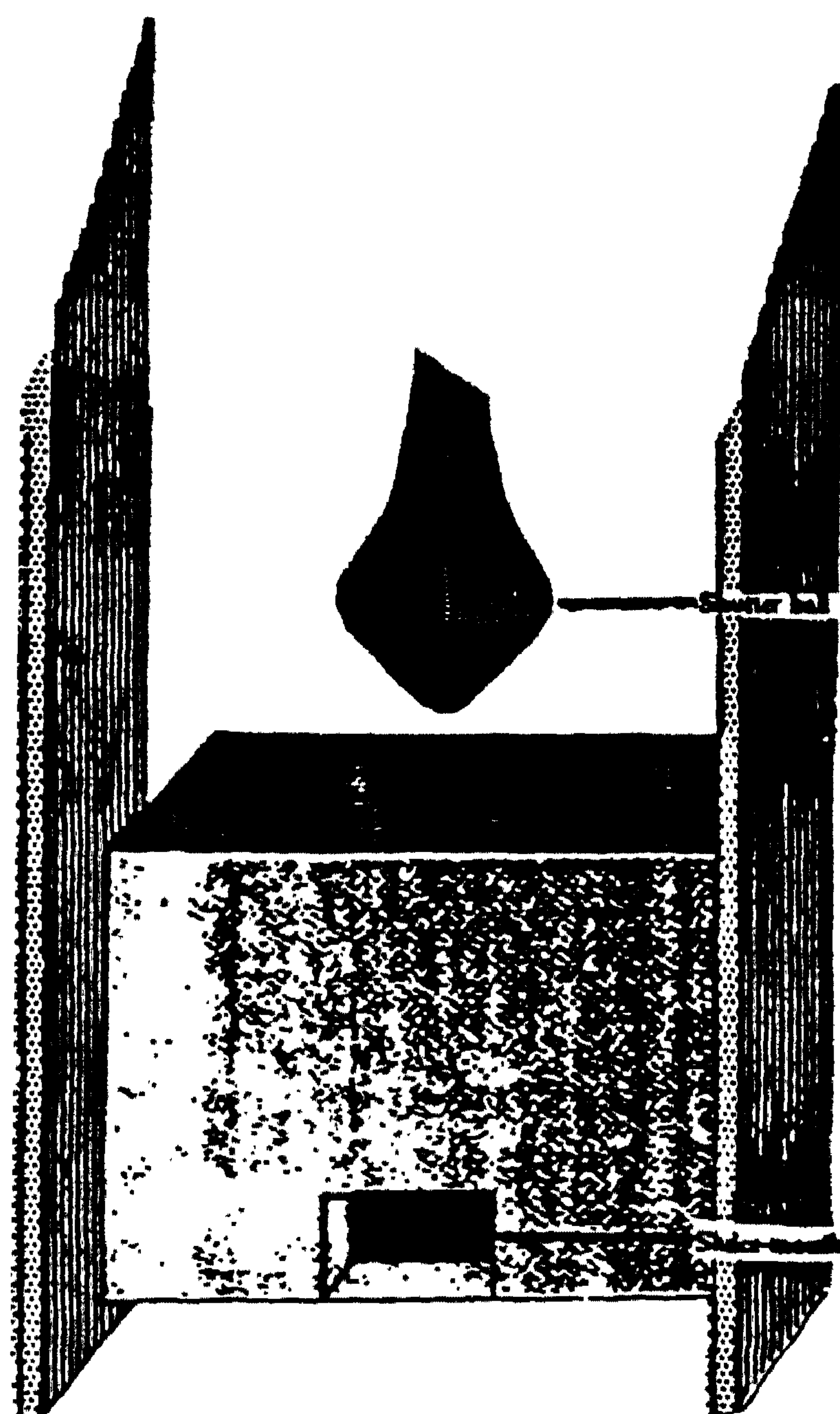


Fig.2. Kumiḷi (sluice-pit) system (reproduced from Studies in History, Vol.2, No.2, 1986)

from the ground level. It had openings at its base into channels running in various disections. The flow of water through the channels required no contrivance since it worked on gravitational force.

"The sluice-pit" (*kumiḷi*) was another system (*Fig.2*) for the regulation of the flow of water from the reservoir, used at required centres. In this case, the sluice-mouth was a pit, also enclosed and with a circular opening on the surface. The rod lowered through the cross-slabs in the system must have been connected to a global stone or wood that acted as the shutter. Here the difference was in the nature of the valve of the sluice. In the case of the *tūmbu*, water from the reservoir flowed into the sluice from the side and, in that of the *kumiḷi*, from above" (Rajan, 1986, pp. 160-161).

Canals

The canals system of irrigation probably had its beginnings in the use of artificial water courses by the Vedic people. The word *kulyā* (*ṚV.* III, 45.3; X.43.7) refers to artificial courses flowing into a river. The expressions *khanitrima* meaning 'produced by digging' as an epithet of *āpaḥ* 'waters' clearly refers to artificial water channels used for irrigation. Such artificial canals were dug by using a tool called *Khanitra* (*RV.* VII. 49.2; *AV.* I. 6.4). Rituals were practised before leading the river water into the canals (*AV.* III. 13; I. 6.4; XIX. 2.2; Ramgopal, 1953, p. 133). Kauṭilya classifies the countries making use of the water channels in agriculture as *kulyāvāpāṇam* (*AS.* II. 24.116, Shamasastry (tr), p. 130). Patañjali in his *Mahābhāṣya* speaks of canals for irrigating paddy fields *śalyartham kulyāḥ* (Patañjali I.1.24; I. 82, *see also* Agrawala, 1953, p. 204).

In Sanskrit literature the expressions such as *nāla*, *nālika*, *praṇāḷi* are used to designate different types of canals, drains and channels and these unmistakably point to the existence of artificial water-courses used in irrigation in North India. The canals which also helped to stop inundation by rivers are referred to as *Jalanirgamaḥ* (drains) in the *Amarakośa* (9.7; 9.36).

A survey of South Indian epigraphical evidence shows that a number of canals and channels bearing different names would indicate their specific use. The reason is that in the South each agrarian unit had a network of channels to supply water in each field, leading either from the river or the village reservoir. Generally the canals were known as *vāykkāl* (Tamil) and *kāluve* (Telugu and Kannada) (*SII.* II. Nos. 4 & 5). In the Tamil speaking areas the channels were dug from every conceivable source, natural or otherwise. The channels dug to bring water from the rivers to feed the tanks in the vicinity were known as *ārruk-kāl* (*SII.* II. p. 352). In the days of the Pallavas, there were native channels (*nāṭṭukkāl*) dug from the river Palar for irrigating the adjacent fields (*SII.* I. p. 150).

The high level channels *meṭṭu-vāykkāl* or *mugattu-kāl* (*SII.* II. p. 435) were expressly dug to conduct water from the tanks to water the fields. The drinking water channels cut from the rivers and tanks were specifically known as *sennir-poduvinai* and for digging such channels there was a provision of free labour known as *sennīr-veṭṭi* or *sennīr-amañji* (*EI*, XVIII, p. 124; XV, p. 72).

Branch channels from the main canals and tanks were variously named as *kurangāru*, *kāl* and *kilai-kāl* (*SII*, II. p.352, III, p.106 & 154; *EI*, V. p. 49). Similarly, the field channels flowing towards the fields in a village were either called *kai-yāru* or *ahai-vāykkāl*. Small irrigation channels issuing from the reservoir was known as *kaṉṉāru*. The famous Vairamegha *taṭāka* constructed by the Pallava Dantivarman (c. 795-845 A.D.) had three branch channels and as many as twenty five such *kaṉṉārus* taking water from this tank and watering the fields in and around Uttiramerūr (Chingleput district). This is attested by a number of Pallava and Cola records.

Feeder Channel

Feeder channels were dug from rivers to feed tanks which in turn were used as the main source of supply to fields by means of branch channels. Such a channel is mentioned in a record of the Pallava Parameśvaravarman who dug a feeder channel from the river Pālār to feed the Paramesvara *taṭāka* which was constructed by him at Kāñcīpuram (Cingleput district) in the 2nd half of the seventh century A.D. (*SII*. I. p. 154). From the Udayendiram grant of the Cola Parantaka I (920 A.D.) we learn that a feeder channel was constructed to the tank at Vinnamangalam (Ambur, North Arcot district) (*SII*. II. p. 389).

Among the many feeder channels dug in the extreme South India, the Uyyakoṇḍān Channel dug by Rājarāja Cola I (c. 985-1013 A.D.) is an important native irrigation work which is still serving the district of Tiruchirappalli. This channel branches off from the Kaveri near the Veṭṭuvāyttalai Railway station, supplies water to a good portion of the district and eventually falls into a large tank in the village Valavandān-koṭṭai, about 10 miles to the North-East of Tiruchirappalli. Robert Sewell remarks "there is no doubt that the channel is a very old work" (*ANRIE*, No. 72, 1890; *SII*.IV, No.396,p. 120; Sewell, I, p. 269).

Inundation Canals

The method of irrigating fields through inundation canals is indeed very ancient. Though the northern source materials are silent about this practice, but considering the geographical conditions and the river systems, the inundation canals dug from the rivers for irrigation purposes must surely have existed in many parts of north India. In the south, irrigation by means of inundation canals was quite common in the days of the Pallavas as evidenced by the records of the period. Shallow cuts are made through the river banks (*kulai*) into which the excess water flowed when the level of the water in the river rose higher in the floods which occur during the monsoon seasons. Usually the head of inundation canals are made on the exact or correct bank of the river from which they draw their supply. In the past, such spots were selected by experience only. In one of the records of Nandivarman Pallavamalla II we notice that the settlers of the newly constituted village were permitted to make inundation canals (*vellakkāl*) on the banks of the rivers Vegavati and Pālār and irrigate all the fields within the village. Though the use of such canals must have been extensively in vogue in other parts of India, but we hardly come across any references to such canals in the records (*SII*. II. p. 352).

Spring Channels

Spring channels (*ūrrukkāl* in Tamil and *ūttakālva* in Telugu) were also made use of for irrigating small parcels of arable lands and for collecting drinking water. They were made on river- beds, but the practice was not widespread because of the non- availability of sufficient underground water during the hot seasons. Deep furrows were made on river-beds and water thus collected was channelised to the fields. The practice of collecting water from springs was quite prevalent during the days of the Pallavas whose records say that permission was granted to donees to dig *urrukkāl* from the beds of the rivers Palar and Vegavati (*SII.* I.p. 151). Even now such channels are found on the beds of the Pālār and other rivers in South India.

No tangible evidence is forthcoming from the above account regarding the materials and methods involved in the construction of canals. We shall now turn to archaeological evidences which throw much light on the ancient canals and their structural details. The interesting aspect is that each canal has its own distinctive features.

Besnagar

Excavations carried out by the Archaeological Survey of India in 1914-15 on the western bank of the river Bes at Besnagar, near Bhilsa (Gwalior), have brought to light the remains of an ancient irrigation canal (c. 300 B.C.). The masonry canal was 7 feet wide and 5 feet 6 inches high. The north-south limb of the canal was 185′ 4", whereas the east-west limb could not be traced, since both the walls were broken off at the same point where the canal took a turn.

Most probably it extended as far as the Bes river which is hardly 2 furlongs away from the site. The masonry walls were plastered with lime mortar of a superior quality. D.R. Bhandarkar who supervised the excavation work opines that on chemical analysis it was found to rival that of the Romans. The use of such quality lime mortar is not only appropriate but essential also for such brick walls, which, otherwise, would have been easily destroyed by the percolation of water. The walls were deliberately sloped downward to counteract the pressure of water. Traces of a flight of steps found at the middle of the south wall of the canal suggested the various uses of the water that was flowing in the canal. That the canal served as a storage canal was indicated by the cross-wall joining the north-south walls at the end. By the application of suitable lifting devices water must have been raised from this canal to irrigate the surrounding area (Bhandarkar, 1914-15, pp. 69-71).

Kumrahar

A canal dating back to the Mauryan period was unearthed at Kumrahar, a village 3 miles to the east of Patna Railway Station. It was found along with the Mauryan wooden pillared hall and hence belonged to the same period. The canal was 43 ft. wide and 10 ft. deep at the centre. A.S. Altekar states that "this canal was ultimately connected with the Ganga and might have been used to waft, the huge pillars direct to the door of the hall from the chunar quarries where they were probably prepared" (Altekar and Mishra, 1959, pp. 25-30). Hence it is not possible to say whether the canal supplied water for irrigation of lands in the vicinity.

Ujjain

At Ujjain, a brick-lined channel 36 ft. wide at the top and 8′ 6" at the base (bottom and foundation) was exhumed to a length of 150 ft. which ran south-west and north wards. The limited excavation did not reveal its connection with the river 'Sipra' which is quite close to the site. At the start of the canal there is a big pond like natural depression suggesting to be the feeding agency. It cannot be said with certainty whether this canal was meant for storage purpose or for irrigation (Banerjee, 1957-58, *IAR*, p. 38).

Kāveripūmpattiṇam

Kāveripūmpaṭṭiṇam or Pūmpuhār, the celebrated port city of the early Colas, is now an insignificant fisherman's hamlet on the eastern coast of Tamil Nadu when the river Kaveri joins the sea. Detailed excavation conducted by the A.S.I. at three places at Kāveripūmpaṭṭiṇam had brought to light, among other important monuments, an elegant structure - the water-reservoir at Vāṇagiri (*Fig.3*). Situated about a mile away from the sea, it was made of an earthern (24" × 16") bund with a facade built of bricks. It was beautifully designed with two graceful curves to receive the water and let into a pond. Probably it was a small feeding channel from the river Kaveri or its numerous off shoots. The paved inlet channel was covered by a corbelled arch (Raman, 1968, p. 239).



Fig.3. Outlet channel of a reservoir, Vāṇagiri, Kāveripumpaṭṭiṇam (photo courtesy : ASI Southern circle)

Nāgārjunakoṇḍa

The ancient canal at Nāgārjunakoṇḍa, datable to the 3rd or 4th century A.D. when the Ikṣvāku dynasty ruled over the parts of Āndhradeśa with their capital at Vijayapuri in the picturesque valley is another example. "The exposed canal runs

to a length of more than 800 yards flowing east-west with an average width of 50 feet and 6 feet depth. The embankments were constructed with a hard lime stone gravel with *Kaṅkar* and stones which were rammed to withstand the rush of water. They were gradually sloped to the canal bed which also contained similar flooring. In addition to this the southern side embankment was further strengthened by a random rubble wall of 4 feet wide" (Subrahamaniyam, *IAR*, 1958-59, p.8). The canal was built of large-sized bricks (12 × 12 × 3) and of extremely durable nature. Though the purpose of such a big canal as this is not clear, it can be reasonably surmised that it served as a water source for the dwellings in the vicinity, and other public use, in particular to the famous stadium, the Harati temple, great bath, etc. (Subrahmaniyam, *IAR*,1954-55, pp.22-23).

Embankments

Embankments form an essential part in the construction of river banks, canals, and reservoirs. They are artificial wide wall of stone or earthern mounds which are built to keep the rivers, canals and tanks from overflowing the banks. They are essentially constructed to impound water and also to increase the storage capacity of reservoirs. The artificial embankments were used in the Vedic period.

They are mentioned in association with dams or barriers in the *Ṛgveda* as *Kṛtrimāṇi rodhāsi* (*ṚV*. II. 15.8). The embankments surrounding the rivers with whirls were known as *rodha cakraḥ* (*ṚV*.. I. 190.7). They were, no doubt, earthern without regular masonry. So the idea of erecting embankments was current in those days and actually practised.

Kulai and *ārrukkulai* are the terms in Tamil used to denote the tank bund and river embankments respectively (*ANRIE* No. 292, 1908; *SII*.V.p. 603). The inscriptional evidence in Tamil clearly shows that the embankments of tanks were allowed to be raised within their limits to hold the maximum quantity of water. The Tiruvālaṅgadu plates of the Cola Rajendra I, for instance, the following specification: "the embankments of the tanks of this village shall be permitted to be raised within their (own) limits (to any suitable height) so as to hold the utmost quantity of water that may be let into those tanks" (*SII*. III, NO. 205. 11. 426 ff.; also *ANRIE*, No. 103, 1921).

We get a few references from the inscriptional sources about the material involved in the construction of embankments. While recording the restoration of the famous Sudarśana lake by Rudradaman I, the Junagadh inscription says that its embankments are stony, in breadth, length and height constructed without gaps as they are of stone (clay)" (*EI*. VIII. No. 6, p. 46). We do not know when the great embankment, over 100 feet thick at the base, finally crumbled. During the days of the Cola Karikāla the Kaveri was impetuous and of considerable magnitude. The Ceylon Chronicle *Mahāvaṃśa* says that he invaded the island of Ceylon (Sri Lanka), carried away about 12,000 captives and set them up to work on the construction of the banks which extended along the course of the river to a distance of about 100 miles from its mouth (Kanakasabai Pillai, 1904, pp. 8-9). This is well reflected in an eleventh century epigraph. "He (Karikāla), who curbed the pride of the subordinate, prevented the Kaveri, which by its extensive floods caused the

earth to be deprived of its produce, by means of a bund formed of earth thrown in baskets carried in hand by (enemy) Kings" (*TRV. III*, pp. 154-155). This age-old and time-tested method of strengthening the river banks is still being adopted in rural area in South India. The excavation conducted by the Archaeological Survey of India since 1915 have clearly established that canal embankments were constructed with hard lime gravel mixed with stones which.were rammed to withstand the rush of water. Bricks of unusually large size 24" ×12"×3" and of extremely durable nature were used in the construction of walls. Evidences show that in the later centuries the river banks or tank embankments were either raised out of earth or reinforced with stone revetment. In some cases granite stone blocks were used for the basement of embankments (Karthikeya Sharma, 1958-59, pp. 307 ff; Raman, 1968, p. 239).

The unabated technical skill of the tank builders in ancient India will be fully realised if one could make an *in situ* study of some of the tanks which still exists even to this day to afford irrigation facilities. A.F.Cox in *North Arcot District Manual* describes the Mahendra Taṭāka excavated by the Pallava Mahendravarman I in Mahendravāḍi (North Arcot District) thus: "The bunk (manmade embankment), is enormously high and might be restored to its original height, in which case a great extent of land could be brought under irrigation" (Cox, II. pp. 438 ff.). The tank at Kaveripakkam constructed by the Pallava Nandivarman III (c. 844-856 A.D.) is the largest tank in the same above mentioned district. Its extensiveness is exhibited by a "bund about four miles stretching from North to South" (Cox, II. pp. 438 ff). The bunk of the Viranam tank created by the Cola Parāntaka I is ten miles in length, and has mean width of above 3 miles. The large irrigation reservoir "Colagaṅgam" created by the Cola Rajendra I near the capital in the Tiruchirapalli district has an embankment of sixteen miles long running from north to south and provided with several sluices and channels for the irrigation of a large area (Nilakantha Sastri, 1955, p. 234).

Trees on the Banks of Tanks: The practice of planting trees on the taṅk bunds was in vogue in ancient times. The Sudarśana lake which was destroyed by a storm during the reign of Rudradaman in A.D. 150 was restored to its original glory by strengthening the dam and planting trees on all banks. In some places particularly in Āndhradeśa rows of trees called *Kaṭṭava* were planted on or by the side of the tank bund, evidently with a view to adding to its strength (*CTI.* No. 53; also Yazdani, 1964, p. 679). In Tamil country five fruit bearing trees, the Indian gall-nut, Nelli (*Phyallanthus embalica* or the *embalika myrobalam*), Tantri, Karañja-puṅga (Indian beach *Pungania glabra*) and Aśvatha (the Fig tree or *Ficus religiosa*) were generally planted all along the bunds of tanks. The principle which underlies the planting of such trees on the bunds of tanks is easily intelligible.

Trees arrest the soil erosion due to sudden or frequent floods and also hold up the water level which would fall without the banks. Hence the presence of trees near the tank was found very useful. Moreover, they contain some tannin in them. The tannin adds a slight sweet taste to the water and thus masks any excess of chlorine in drinking water. "It is also useful in cleaning the water of its impurities on the surface by carrying down to the bottom all dirt and clay

that the water may contain, thus serving the same purpose as alum". Hence these trees are generally planted near the bunds of drinking water tanks" (Venkatarama Iyer, 1916, p. 184).

Dykes

Dyke is a thick bank or low wall or embankment built to control water and prevent flooding. It is also a narrow passage or water- course dug to carry water away. Besides the use of canals and wells for irrigation, the construction of dykes (*setu*, which also stands for a dam) was known and used in ancient times. The importance of the construction of dykes is duly recognised by the *Smṛti* writers. Narada (*Nārada smṛti*, XI. 18) classifies the dykes according to their utility. Two main classes of dykes are mentioned in the *Nārada Smṛti* (XI. 20-2), namely *Kheya* which is dug into the soil in order to drain off excessive water and another called *bandya* which is constructed as an embankment to prevent water from flowing away. The former serves the purpose of irrigation and the latter protects the fields from excessive water.

Both Yājñavalkya (*Yājñavalkya Smṛti*, II. 156) and Nārada (*Nārada smṛti*, XIV. 17) state that the erection of a *setu* made by the owner of one field in the neighbouring field should not be forbidden by owner of that field, if the loss of soil it causes (to the latter) is small as compared with the great benefit that it may offer. They also prescribe that one should make a dike or water-course on another's land with the permission of that man or with the permission of the king as otherwise he cannot reap the benefit thereof. In South India such types of dykes might have been used for agricultural purposes; but we hardly come across any reference to them in inscriptions.

Wells

Well is a place where water comes from underground. Almost in all possible nook and corner of every village in India one finds the use of a well for irrigation and drinking purposes. Well irrigation no doubt extends the distribution network but slowly. However, it was common in those days, as it is today, to have a well dug in the midst of fields. Well water was utilised in the areas where the tank or canal irrigation was impossible or totally absent.

The discovery of a large number of wells within the housing complex at Mohenjo-daro points to the importance of well-water for domestic and ritualistic purpose. The occurrence of the word *avata* meaning a well repeatedly in the *Ṛgveda* (*ṚV*. I. 55.8; IV. 17.16; VIII. 49.6; X. 25.4) shows that the vedic farmers had known the method of digging wells. Such wells are described as unfailing (*akṣita*) and full of water (*ṚV*. X. 101.6).

Sometimes those wells appear to have been used for irrigation purposes, the water being led off into broad channels, *sūrmī susirā* (*ṚV. VIII.* 69.12; Macdonell & Keith, 1, pp. 39-40). Deep sunk wells whose bottom looks dark due to their depth are mentioned in the *Jaiminīya-Brāhmaṇa* (I. 292), a work related to *Sāmaveda*.

In the days of the Mauryan rulers, the farmers had to pay a revenue tax of 1/4 of the produce for using wells fitted with machines (*AS. II.* 24.117; *see also* Shama sastry, Eng. tr. 1967, p. 131). Pāṇini's *Aṣṭādhyāyi* (IV. 2.73-74) mentions two types of wells: *karkaṇḍu* and *sakandu*. He also mentions wells on the banks of the river Vipāsā (Beas). Those dug on the right bank of the river were permanent wells, and those on the left bank were temporary ones subject to annual inundations.

In the early Tamil anthologies the expressions such as *kūval, kulam, kiṇaru, ūruni, vāvi, keni* and so on are mentioned to signify a well (*Maṇimekalāi.* VII.76; *Tirukkural,* No. 523; *Puranānūru,* line, 132-133; *Paṭṭinappālai,* line, 244, *see also* Aiyangar 1928). These terms were evidently used to indicate variations in size and economic importance. One of the oldest regions in South India is the Koṅgu region (modern Salem and Coimbatore districts of Tamil Nadu). Although this region was watered by the Kaveri and its numerous tributaries, water scarcity was felt very much at all times. "The skill and energy with which the people of Kongu sunk very deep wells and brought out water by breaking hard rocks with their pickaxes drew the admiration of the ancient bards who celebrated them in their songs.

The wells supplemented to a great extent the limited water-supply of the people to convert arid tracts into arable land" *(Subrahmanya Aiyar, K.V. II, p. 45*). The Tamil epic, *Manimekalāi,* mentions a well (*endirak-kiṇaru*) which was provided with filling and discharging pipes for conveying water (*Maṇimekalāi,* XIX. 102, *see also* Aiyangar, 1928).

The lithic records from the north refer to two distinct types of wells - *kūpa* and *vapi*; the former is an ordinary well, while the latter appears to have been equipped with flights of steps and used for a tank of the smallest size. The South Indian records mention specific names to denote the wells the purpose for which they were put into utility - *pānīya-kūpa* (drinking water well), *uruni-kulam* (public water tanks), *tirumañjana kulam* (sacred tanks for use by the temples), *puravai* and *kinaru* (ordinary well), *puṭṭai-k-kiṇaru* (wells fitted with water-lifts) *turavu* (large wells for irrigation) and so on (*EI.* VIII. p. 145; *SII,* II. Nos. 4, 5, and 445; *IPS.* No. 156; *SII.* III. No 4; III. p. 102). The *paṭṭinappālai* (Chelliah, 1947, p. 48), one of the Tamil anthologies, records that in the outskirts of the city of Kāveripūmpaṭṭiṇam the inside of wells (*urai-kiṇaru*) were covered with baked clay instead of being built with stones. It is interesting to note from the Kannada inscriptions that the charity wells set apart for thirsty way-farers and cattle were specifically names as *arabāvi* (*SII.* XVII. No. 58. p. 68).

According to the *Dharma Śāstras,* the man-made receptacles are of four types *kūpa, vāpi, puskarinī* and *taḍaga.* The *kūpa* as a well is from five to fifty cubits in length (if rectangular) or in diameter (if circular). It has generally no flight of steps to reach the water. *Vāpi* is a well with a flight of steps on all four sides or on three or two sides or one side only and its mouth may be from 50 to 100 cubits; a *puṣkarinī* is from 100 to 200 cubits in length or diameter and a *tadaga* (a tank) is from 200 to 800 cubits. The *Matsya Purāṇa* states that a vāpi is equal to ten *kūpas* in merit (Kane, 1973, II, p. 893).

The *Viśvakarma Vāstuśāstram* (p. 51) clearly describes the *vāpis.* "Small tanks (*vāpis*) may be square, rectangular or circular in shape and their dimensions may be from 3 to 10 *daṇḍas.* It is enclosed by walls and has springs on all the four sides.

They are built down to a depth of about 10 cubits below the spring. They are also provided with bathing ghāṭs on all the four sides suitable for sporting in water. On one side of the tank shall be built a water-lifting device".

Water-divination: If we are to take water divination as part of well irrigation, then we may say that water-divination is an important and independent science practised in ancient India to locate and avail the water sources from the subterranean region. The expression *dakārgala* means a branch of science dealing with water locked up or imprisoned in the bowls of the earth. Those who practised this science were known as *kūpadarśakas*. They leaked out a living by private practice for they paid taxes. It is believed that they might have been working as inspectors of wells in those days.

Varāhamihira's *Bṛhat Saṃhitā* (*Bṛh.S.* pt.1, ch.LIV. pp.499-526 (Eng tr.) by V.Subrahmanya Sastri and M.R.Bhat,1947) prescribes certain asterisms that are beneficial for sinking wells: They are *Rohiṇī*, *Puṣyā*, *Maghā*, the three *uttaras* (*Uttaraphālgunī*, *Uttaraṣaḍhā* and *Uttarabhādrapadā*), *Hastā*, *Anurādhā*, *Dhaniṣṭhā* and *Śatabhiṣaj*. The author gives effects of sinking wells in the different quarters of a village or town. He says that wells sunk in quarters other than south-east, south-west, north-west, would lead to auspicious results.

As far as our evidence goes, the wells discovered at Mohenjo- daro are the finest examples from the point of structural details. Water for domestic use was mainly derived from them. Every house had a well of its own. A public well was frequently placed in a *cul-de-sac* between two houses. The exposed wells are generally circular. Considerable variation is seen in the diameter of the wells and the sizes of the bricks used to construct them. Generally, the wells were 3 to 4 feet in diameter. The bricks used in the construction of wells were moulded and burnt and are uniformly wedge-shaped. The wider end of the bricks in the steening of wells were carefully curved so as to present a smooth surface on the outside of the well. Mud mortar was the only cement used to bind the bricks. The pavements of bricks laid around the wells generally sloped towards a drain at one corner to allow waste water to run away. In many cases the top of the well only projected above the floor of the chamber in which it was situated, and a edging of brick around it served to prevent waste water from re-entering the well.

In some of the private wells the water may have been lifted by some form of windlass, since there are no friction marks on the coping, which are clearly seen in most of the public wells. On the other hand, the private wells are generally small in diameter and water could be lifted from them by the drawer standing straddle-legged over the well (Marshall, I, pp. 269-70).

Among the numerous extant wells in the South, the best preserved example is the *Mārpiḍugu-perun-kiṇaru* (*ANRIE*, No. 541, 1905; 1905-06, pp. ii. para 4, p. 63; *SII*, XII. No. 40, p. 16; *EI*, XI, p. 145) at Tiruvellarai (*Fig.4*), 14 miles to the north-east of Tiruchirapalli (Tamil Nadu). The well, now popularly known as the *Nālumūlaik-keṇi* (four-pronged well), is very interesting from the point of view of history and antiquity. The construction work was commenced in the fourth year and completed in the fifth year of the Pallava Dantivarman (A.D. 799-800). The shape of the well is in the pattern of a *Śvastika* with four entrances facing the four directions. From each entrance a flight of steps leads to the interior of the well. The

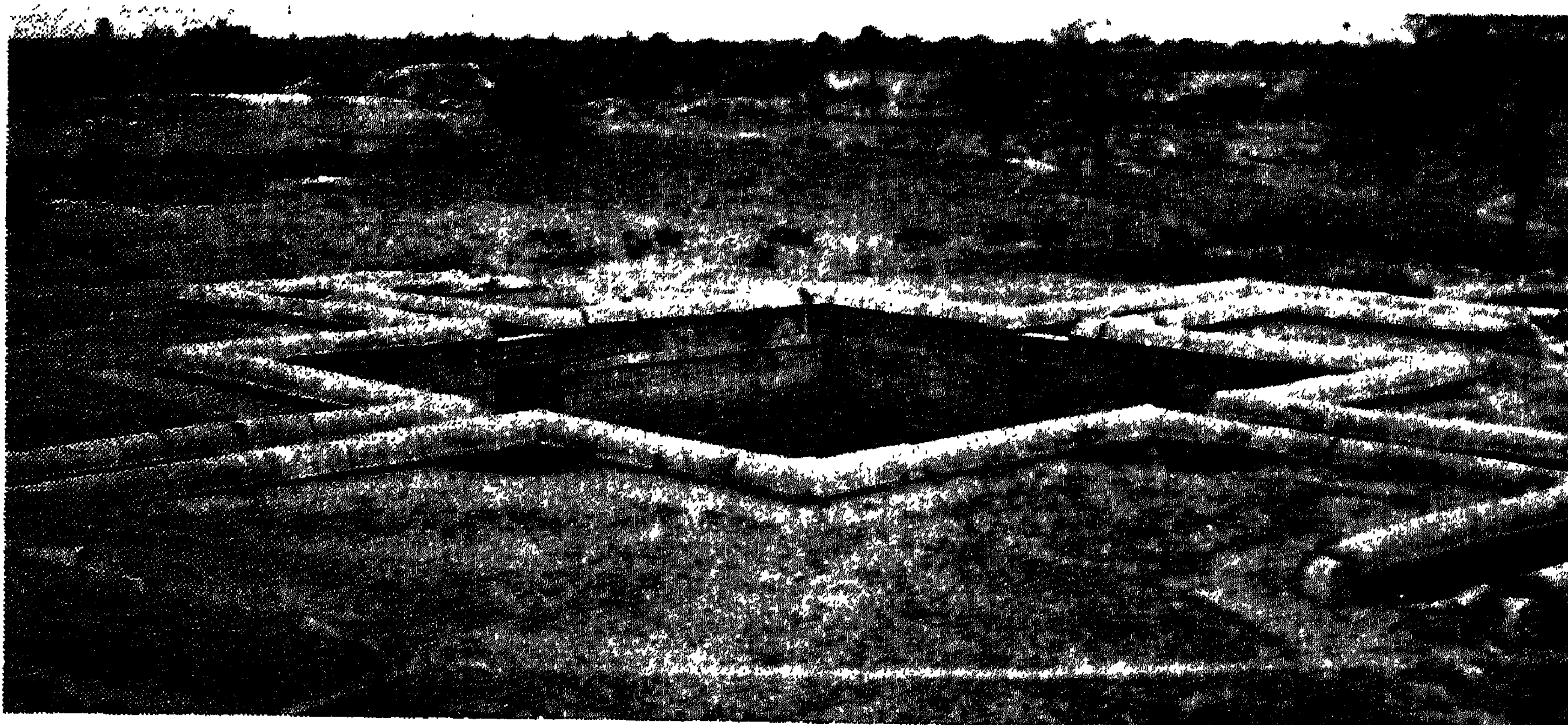


Fig.4. Mārpiḍugu-perunkiṇaru (big well), (photo courtesy: Dept. of Archaeology, Government of Tamil Nadu)

inner face of each of the portals, the outer wall and the margin of the well are constructed out of dressed granite blocks. The capacity of the well is judged by the time taken for its construction. Its size, 37 sq. feet, suggests that it was used both for supplying water to the temple and irrigating the *devadāna* lands. The well was repaired in the thirteenth century as it had suffered considerable damage from floods and other natural causes. Though the inscriptions record the repairs done to it, the well does not appear to have undergone any major structural change. Even now the well is being used for irrigation and domestic purposes.

Water-Lifting Devices

The origin of the *Yantras* or mechanical contrivances for lift irrigation in India is obscure, because of their great antiquity. R.J. Forbes (1965, II. p. 32) believes that, "such machines existed in the later stages of antiquity and they were developed from the simple ladle gourd or vessel used to collect water from stream or pool. The machinery moved by beast or men was finally driven by force of the river alone, by water-wheels".

To make an enquiry into their evolution, it would be difficult, because different devices ranging from the simple basket to the water-wheel had no doubt been used in olden days side by side and remained in practice up to the present day. The first known mechanical aid practised in ancient India was the bucket-wheel or the water-wheel. The earliest evidence of the existence of water- lifting devices is furnished by the antiquities unearthed from the Mohenjo-daro and Harappa excavations. Sir John Marshall who studied the pottery evidences from Mohenjo-daro expresses his opinion about the possible use of pottery for water-wheels (Marshall, 1931, I, p. 318). His view amply finds corroboration in the remarks advanced by Ernest Mackay who says that, "though there is no direct evidence that the water-wheel was known to the people of the Indus Valley the shape and make of these jars certainly suggest that why such a number were made

and broken" (Mackay, 1948, p. 120). It is thus quite discernible that some technically advanced devices were put into practical use during that period.

In the Vedas, mention is made of wells, canals and dams. That is to say, the Vedic Aryans did not entirely depend on rainfall alone for agriculture, but some definite artificial devices were used by them. In the hymns of the *Ṛgveda* the uses of mechanical contrivances for drawing water from deep and goodly wells are well narrated (*ṚV*. X. 101.5-7). The contrivance with a stone wheel as mentioned in the same *Veda* is known as the *aśma-cakra* (*ṚV*. 101.7). In other places we are informed of the use of machine, *ghaṭi-cakra* or *ghaṭi-yantra*, for lifting water (*ṚV*. X. 93. 13).

The mechanical contrivances worked by animals, particularly bullocks, were also clearly known and made use of in ancient India as early as the fourth century B.C., as indicated by the term *yugavaratra*. But Pāṇini, the celebrated grammarian, has mentioned in his *Aṣṭādhyāyī* (IV. 2.45; *see also* Agrawala, 1931, p. 204) the *yugavaratra* to mean the yoke and the rope or strap by which the bullocks were driven for raising water. The word *udamcana* denotes a large earthen bucket which must have been used to lift water from wells for irrigation (*AŚ*. III. 3.123).

During the days of Candragupta Maurya there was an elaborate system of irrigation which is wholly attested by Kautilya's *Arthaśāstra* and the *Indica* of Megasthenes. Though Megasthenes has described at length about the facilities provided for irrigation, yet he has not made any attempt to mention the mechanical water- lifters.

The water-rates (*udakabhāgam*), according to the *Arthaśāstra* varied with the modes of irrigation, which were four in number, viz., (1) *Hastaprayartimam* - that is drawing water with the hands and carrying it to the fields in pitchers, etc.,(2) *Skandhaprāvar timam - by carrying water on the shoulders or the necks of bullocks (water-lifts worked by bullocks)*; (3) *Srotoyantraprāvar-timam* - a mechanism for lifting water from the channels (kulya); and (4) *Udghāṭam* - the water-wheel for raising water from rivers, lakes, tanks and wells, *nadīsarasaṭātakakūpadghatam* (AS. II. 24.41; *see also* Kangle, *1963, p. 173)*. These four types of irrigation as mentioned in the *Arthaśāstra* must have been classified for the convenience of taxation and a close study of them would prove how methodically Kautilya had arranged on the basis of their merit, efficiency and the extent of the area of irrigation. Bhoja's *Samarāṅgana-sūtradhāra* describes a few types of water machines, *vāri-yantras*, but the text does not give a systematic classification of all the *yantras* (Shukla, 1960, I. p. 382).

In the southern part of the sub-continent there were also water- lifting devices prevalent from the very early centuries of the Christian era. But the *Saṅgam* literary works, from which we derive materials for our study on the subject, do not clearly mention the provenance of the use of such devices.The application of water-lifters and other simple devices are, however, unmistakably mentioned in the literary works such as the *Akanānūru*, the *Maduraikāñci*, the *Śilappadikāram* and the *Manimekalāi*, the twin epics in Tamil, the *Periyapurāṇam* and so on.

In the *Śilappadikāram*, the poet Ilango Adigal, while giving a detailed account of the Kaveri describes the modes or devices, particularly the bucket, the water-lifts and palm-leaf baskets. In the tenth canto of the work it is thus described: "By finding

her (Kaveri) movement arrested by the barrier - the anticut with its doorway - she noisily leaps beyond it in the sportive mood natural to her first freshes. No sound other than this can be heard. We can hear neither the sound of the bucket nor of the water-lift; neither the usually loud, *picotaḥ* nor the palm-leaf bucket used in irrigation" (*Śilappadikāram*, X. 107-119; *see* Ramchandra Dikshitar, Eng, tr. p. 161).

A passage like this would surely indicate the existence of water-lifting mechanisms for the purpose of irrigation and cultivation. In the *Maduraikāñcī* we get a glimpse of the modes or different types of water-lifting devices employed in irrigation: "In thy domain is heard the sound of those who stand in rows and irrigate their fields from tanks with basket-pails to well-sweep tied and baskets strongly made and softly bound" (*Maduraikāñcī*, ll. 89-92; *see also* Chelliah 1947, p. 237)[3].

In the text the words *āmbi* and *kilar* stand for baskets, pails and buckets (*Maduraikāñcī*, I. 89; *Śilappadikāram*, X. 107-119). They suggest that different types of baskets and buckets were employed in irrigation. '*Tev*' and '*eda*' are the terms generally met with in the Tamil literary works to denote palm-leaf baskets; and *pilā* (*Śilappadikāram*, X. 111) is also a basket made of metal.

The *Periyapurāṇam*, a compendium of biographical sketches of the 63 Saivanāyanmārs (Saints) also makes reference to *edā-periḍā*. Here the term '*periḍā*' stands for a large 'basket' (Periyapurāṇam, V. 1793, *see also* Sendilvel Mudaliyar T.S. 1930).

'*Ettapulam*' (*ANRIE*, No. 116, 1929) and '*ettapādam*'(*EI*, V. p. 49) are the expressions often used in the Tamil inscriptions to categorize lands irrigated by means of *picotaḥs* (water-levers). Generally speaking, *etta*, *ettam*, or *erram* are the terms current even now in local usage in South India. The importance of *ettam* is well highlighted by Kambar, the author of the *Erelupadu*. In the following stanza of the *Erelupadu* a eulogium on agriculture and the cultivator class, Kambar lays stress on the importance thus: "Let not rain fall: Let the seas and the rivers dry up; Let there be famine every where; Let not each do his respective duty, in the world; Even if all these adverse circumstances happen at the same time, only if the peasants do their duty, water their crops from wells by means of *ettam*, the crop will grow and there will be no hunger in the land" (*Erelupadu*, vs. 39; *see also* Jagannathachariar, 1967, p. 52).

Inscriptions refer to two types of *ettam* like the *kurrettam* and *perettam* and literally they stand for 'small *picotaḥ*' and 'large *picotaḥ*' respectively. Probably, they must have been specifically applied depending upon the extent of wet-lands under irrigation. A Pallava epigraph (*ANRIE*, No. 372, 1911) from Tiruvorriyur in Madras Kampavarman tells us of the lands watered by four *picotaḥ* : "cultivable lands on the banks of the tank Tengeri, to be irrigated by four *picotaḥ* ". Another record (*SII*, XII. p. 93 line 15; *ANRIE*. NO. 180, 1912) from the same place of the Pallava king Aparājita mentions "the land irrigated by two large *picotaḥ*" which by their description must have irrigated large areas of land. The same record refers to two water-levers (*jala yantra*) which appear to have been added as an additional means of irrigation in the village (*Fig.5*). A record (*SII*, III. No. 10. pp. 15-17) of the Rajendra Cola I says that the villagers of Ukkal sold 3,000 *kuli* of land and five

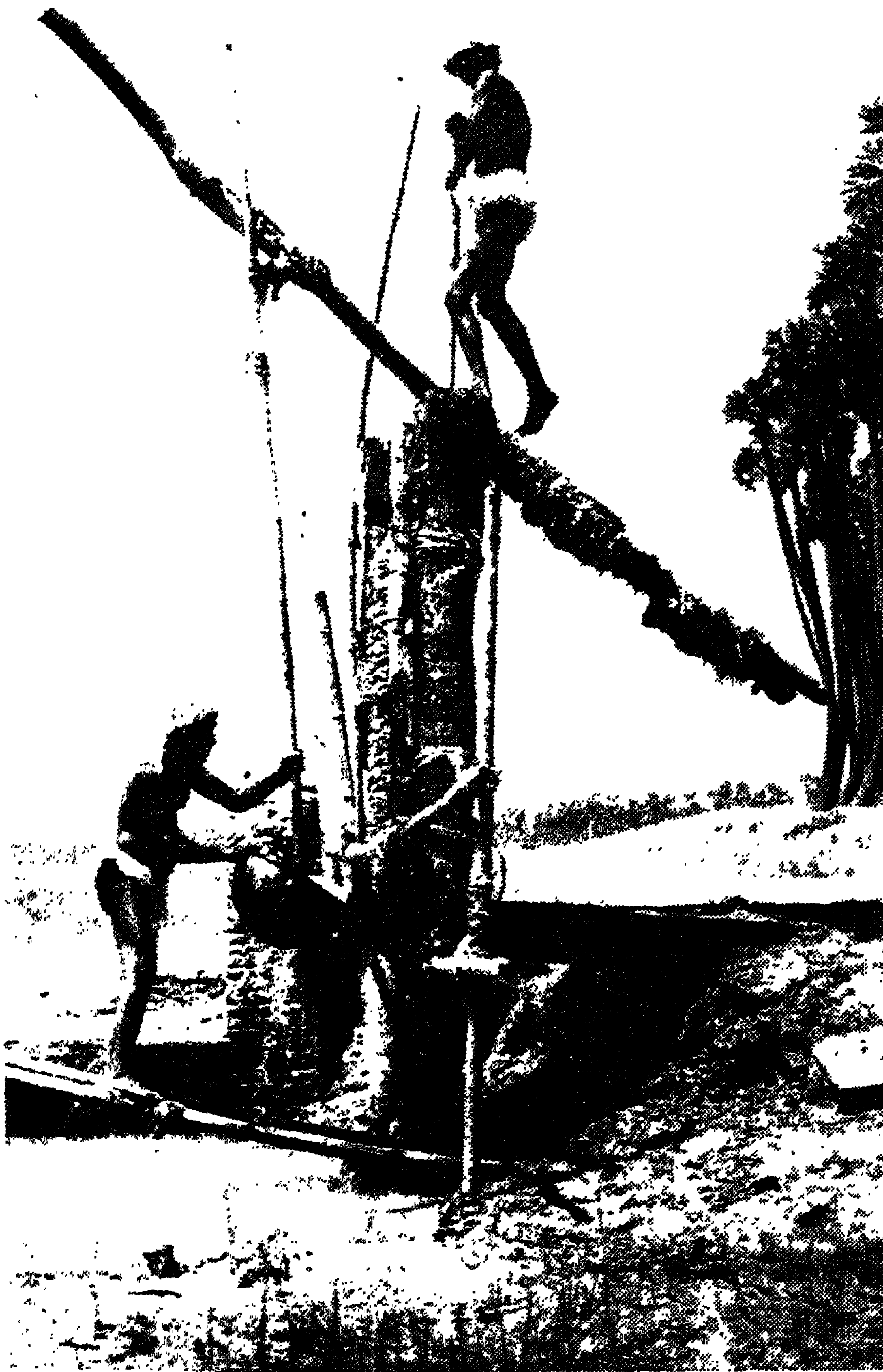


Fig.5. Water-lifting by the Picotaḥ (photo courtesy: M/s G.K. Vale & Co., Madras)

water- levers to a servant of the king who assigned it to the village tank. It is learnt from the Rāyakoṭa plate (*EI*, VII, pp. 48-52) of Skandaśiṣya (fourth year) that such water-levers were also known as *etta-p-pāḍam*. While there are these and other distinct references to the principal types of water lifting devices there is absolutely no full account or description of them in any ancient literary or inscriptional references.

In the preceding pages we have seen the application of various types of water-lifting devices with different names varying with the area of cultivable land in the light of literary and epigraphic evidences. We shall speak of them in detail further on. Only selected devices and techniques have been dealt here with a view to focus attention on the technological achievements of the ancients in this obscure but important sphere of activity. Technically speaking, there can be no doubt about the evolution of devices. On the basis of all available evidences and references, the

methods of mechanisms can be arranged and reconstructed under three broad heads. They are as follows:

(I) Intermittent or discontinuous water-supply from the streams, canals and wells;

(II) Semi-mechanical devices,i.e.,the balanced-bucket; and

(III) Continuous water-supply by water-lifting machinery.

A systematic classification of all the devices used in ancient kingdoms has been done by R.J. Forbes very recently (Forbes, II, pp. 38-39). The list covers all the devices applied at various periods in different countries. But Kauṭilya's *Arthaśāstra* has made a scientific classification of all the water-lifting devices into four broad categories as early as the fourth century B.C. (*AŚ*. II. 24.41). His method of arrangement of devices is fairly in accordance with the methods adopted by modern authors and it still holds good.

(I) Intermittent or Discontinuous Water-Supply from the Streams, Canals and Wells

The three types, the basket, the bag or bucket moved by pulley- wheels and the water from wells by animal power come under this category.

(i) *Basket or Bag* : In ancient India irrigation by means of baskets was practiced from the early days by means of animal power from wells. We have a few definite instances as proof of the widespread use of baskets, particularly those made of palm- leaf, in ancient South India.

Āmbi, *pilā* or *eḍā*, otherwise known as *iraikūdai* in Tamil, was a basket specially employed for bailing out water from deep channels or streams to nearby fields (*Maduraikāñcī*, line 91; Śilappadikāram, X. 107-119). It was made or knotted out of palm- leaf and had a thin rimmed wide mouth with a shallow bottom.

Even now such baskets are commonly found used in South Indian villages. Two factors may be ascribed to the common utilisation of palm-leaf baskets in South India; first, the easy availability of palmyra trees and the second factor is that the baskets are fairly leakproof and durable. In a Tamil inscription (*SII*. II pp iii, p. 352) this method is specifically mentioned as *kūḍai*. "The Vaikhānasas (priestly group of Vaisnavas) of the temple of Mahaviṣṇu arranged for the cultivation of the garden themselves. In order to do this, they employed persons to lift water with buckets, dig the earth, fence the field and do well other connected duties" (*ANRIE*. 1916, pt. ii, para 11).

An inscription (*SII*, XVII. No. 170, *ANRIE*, No. 150, 1904) of Jaṭāvarman Sundarapāṇḍyadeva mentions fields watered with the aid of *ettam* and *eḍā*. It is thus evident that the *eḍā* was one of the simplest contrivances handled by the application of human labour.

(ii) *Pulley-wheels* : The earliest reference to ancient Indian pulley-wheels of stone or wood, similar to those used in modern times, found in the *Ṛgveda* (*ṚV*. X. 101.7) was known as *aśma cakra*; here the word *aśma* stands for stone. That is, the water was raised by a wheel (*cakra*) of stone (*aśma*) to which was fastened a strap (*varatra*), with a pail (*kośa*) attached to it. When raised it was poured (*siñc*) into

buckets (*āhāva*) of wood (*ṚV*. X. 101.7). Sometimes these wells appear to have been used for irrigation purposes, the water being led off into broad channels (*Sūrmī susirā*) (*ṚV*. VIII. 69.12; Macdonell and Keith, I, p. 40). In the Tamil country, the wells fitted with such pulley- wheels for drawing water from them were known as *kilār*. (*Śilappadikāram*, X. 110; *Maduraikāñci*, l. 83). Among the devices invented by the ancients, the pulley-wheel was the simplest one for practical purposes. It was a one-man job to draw water from the well for increasing the flow of water. Obviously, it is the pulley and rope that gave rise to the *mhôte* of Northern India, which was in use for irrigating fields, the rope being drawn by bullocks.

(iii) *From wells by animal power*: Irrigation by means of animal on draught-plane came to be known and practiced in ancient India atleast as early as the fifth century B.C., as indicated by the word *yugavartra* (Agrawala, 1931, p. 204) meaning the yoke and the rope or strap by which the bullocks were harnessed for raising water from wells. The classified modes of irrigation in the *Arthaśāstra* of Kauṭilya brings to light, the word *skanda* which stands for the shoulders or the backs of bullocks. It is thus evident that harnessing animals to the task of drawing water from wells had been conceived quite early, but to our knowledge no ancient representations on stone are traceable of a beast pulling up the bucket. It is also curious to note that water from wells worked by bullocks, now popularly known as *Kapilai-ettam* in South India, does not find place either in the early Tamil works or in the numerous inscriptions of South India. Though the Dosapāḍu inscription (*HRAS*, No. 18) dated A.D. 1254, records the gift of a water-lifting pulley, *rāṭanam*, together with two bullocks, yet it does not disclose the much needed details. Probably this important mode or practice with full improvements may have been introduced into or adapted in South India at a later stage as an additional means of distributing water for irrigation.

Let us examine the actual working of the bullock *mhôte*. In this type, a pair of bullocks move down from the slope, specially constructed to the wall of the well, lifting behind them a bucket or a leather bag which is discharged into the connecting channel by means of a rope. After discharge the bullocks walk up the slope until they reach the top by which time the bucket will have again reached the surface of the water and got filled; and then the process is repeated. This method is not free from the application of human labour; for the man who sits on a seat in between the animals has to conduct the animals properly during the process. Two reasons may be ascribed for the low efficiency of this practice: (1) water flow is discontinuous and insufficient; (2) the time consumed by the animals during each operation is so much that the water-supply hardly covers the required portion of land. And this mode of practice, not withstanding its handicaps and deficiencies, must have certainly given stimulus to the invention of other semi-mechanical and full-mechanical devices.

(II) Semi-mechanical Devices : The Balanced-bucket

(i) *With counterweight* : There were in practice in ancient India two types of balanced-bucket which by its operation and design was semi-mechanical; one was efficiently performed with counterweight, and the other one balanced by the weight

of human body. It has been severally known in different countries to mean this semi-mechanical device, e.g. *shadoof* (Egypt), *dāliya* (Iraq), picotaḥ (South India), *lāt* (some parts of Northern India) and so on (Forbes, II, p. 32). It is generally known in South India as *etta* or *ettamaram* while in the Kannada districts it is called the *rāṭaṇam* (Sharada Raju, 1941, p. 116). In the Tamil speaking areas during the period under review, *ettapulam* and *ettapādam* are the terms used to specify the lands irrigated by means of picotaḥ . Wells fitted with such water-lifts for irrigating the fields were also known as *puttai-k-kinaru*. This is confirmed by a record of the Cola Rajendra I (*SII*, V. No. 489, 1.4).

The device, *shadoof* or *swape*, though an offshoot from the evolution of bucket or pot, is only a semi-mechanized water-hoist worked not by any wheel but by a pair of vertical beams and a horizontal pole. Probably water was raised from wells by means of buckets tied by rope to one end of a long wooden pole, working about fulcrum near the other end that carried a heavy weight.

Let us now go into the details of the actual working of this simple but efficient device. The *shadoof* or *ettam* consists of a long tapering and nearly horizontal pole pivoted on a horizontal beam fixed across two vertical pillars about 8 to 10 feet high which are set up less than a yard apart above the ground. In some cases, granite stone pillars act as the vertical beams instead of the palymra ones. A leather bag of considerable size or a bucket made either of earthenware or metal is hung on a rope or thin horizontal pole from the larger and thinner end and a counterbalance placed on the shorter and thicker end. The counterbalance will always be a block of stone secured tightly at the end. The worker who stands at the edge of the well, pulls down the rope to fill the bucket, after which the counterbalanced end drops and raises the bucket of water to his hand who empties the water in the connecting canal. The process is repeated.

(ii) *Balanced by the weight of human body* : This is the same as the previous one in all respects; but one conspicuous difference is that it is operated with the application of human labour. This type of water-lifting operation is very common even now in Tamil Nadu and some parts of South India. The tapering horizontal pole is worked by trampling along the pole instead of the counterweight placed at the other end. The man who stands and tramples the pole by using his weight must have sure balance and adequate previous experience to operate the device and therefore it requires considerable practice.

The principle of the well-known *picotaḥ* is the same as that of the balance and certainly goes back to early historic times. The change from the system of animal power to mechanical was doubtless an achievement, but the output was limited by the depth of the well. The *picotaḥ* with its rhythm of rise and fall, dip and empty, to which the ancient labourer must have sung as does his modern counterpart, can prove to be much more quicker and efficient than any non-mechanical type of water-lift.

(III.) Continuous water-supply by water-lifting machinery

Wheels of pots or *Water-wheel* : The next and the last stage, technologically speaking, was the fully mechanized water-hoist moved by a water-wheel or wheel of pots. As has been mentioned earlier that the water-lifting device using a wheel

of pots was put into practical application as early as the second millennium B.C. A particular type of pottery, otherwise known as 'scored pottery' found at Mohenjo-daro shows the use of wheel for lifting water.

Sir John Marshall opines that, "some arrangement for drawing water for irrigation, by means of an endless rope working over a wheel, with pottery vessels attached to it at intervals was in use in Sind and other parts of Western India from early times though it may not have taken the form of modern wheel" (Marshall, I, p. 318, f.n). But the excavation finds at other Calcolithic sites unmistakably show that, "only one type of jar has been found broken in large numbers. Jars of this kind average about six inches in height, have a pronounced, pointed and deeply scored belly, and are certainly too large to be grasped comfortably in one hand".

And, according to E.J. Mackay, "they are frequently coated with a thin cream wash, they all have deep spiral grooves round the middle, which would have served to give greater security if they are attached to some kind of water-wheel" (Mackay, E.J. 1937-38, 1, p. 193).

Though the water-wheel "may not have taken the form of modern wheel" but yet it must have had a definite form and shape which by the passage of time had got fully developed into the water- wheel of modern times. At this stage we are at a loss to reconstruct the actual model of the water-wheel used in the Pre- historic period; for the spade of the archaeologist has not exhumed other relevant material evidences than the pottery to throw light on the water-wheel and its essential parts.

In the early Sanskrit works specific names are mentioned to mean the wheel of pots. It is known as *ghaṭicakra* in the *Ṛgveda* and *udghāṭam* in the Arthaśāstra. It has also been mentioned as *jala- yantra-cakra* (water-machine-wheel).

There was a contrivance by name *Araghaṭṭa*, *araghaṭa* or *arahaṭa* for lifting water from wells and canals. The term *araghaṭṭa* has been translated as 'machine-wheel' or 'Persian-wheel'. A large number of lithic records relating to Rajasthan (6th to 13th centuries) refer to the widespread use of '*araghaṭṭa*' as an efficient contrivance for irrigation. "The importance of *araghaṭṭa* may be deduced from the fact that almost invariably they bear separate names and from the social status of the people who seem to have transferred land irrigated by an *araghaṭṭa*" (Chattopadhyaya, Pts II-III, p. 305). While there is no satisfactory technical details relating to the *araghaṭṭa* or *ghatiyantra* available as yet in India, it is not true that these devices were not set up on wells. A recent re-interpreted passage in a Mandasor inscription (Joshi, pp. 214-17) of 532 A.D., referring to a newly constructed well, eulogies its "rotary motions (moving ring) resembling a garland of "skulls" which would continue to discharge "nectar like pure water". More explicit evidence that an *araghaṭṭa*, with its pots, was set up on a well, like the *ghaṭiyantra* of *Amarakośa*, comes from a passage in the *Pañcatantra* (Chattopadhyaya, p. 304). While describing the traditions of Kashmir, Kalhana records in his *Rājataraṅginī* (IV. 191) that "at Cakradhara (modern Tsakadar) he (Lalitāditya 740- 776 A.D.) made an arrangement for conducting the water of the Vitastā (Jhelum) and distributing it to various villages by the construction of a series of water-wheels (*araghaṭṭa*)" (*see also* Stein, 1900, II, p. 428). The above references definitely show that *araghaṭṭas* were set up on wells and river banks. But they do not indicate the use of both chain or rope and gearing mechanism. "To

be set up on a *mahākūpa* (big well), the wheel carrying the pots required the mechanism of a chain but the gearing mechanism, which facilitated the use of animal power may have come at a later stage" (Chattopadhyay, p. 304 f.n.). Based on the above evidences, we are unable to deduce the mechanism of an *araghatta*; nevertheless its operation was distinct from that of other indigenous water-lifting devices.

Archaeological evidence in support of the use of *araghaṭṭas* is available in the form of two sculptures at the Jodhpur museum. They are from Mandor and Saladhi (Pali district, Rajasthan). A panel from Mandor (Agrawala, 1966, pp. 87-88) belonging to the 11th century depicts a 'water-wheel' or *araghatta* with pots (*Fig.6*). The surviving evidence serves to illustrate the most important parts of the wheel. The panel, small in size, depicts a band of warriors, the water-wheel with pots, the operator and an animal in a row from left to right. The right side of the panel shows the wheel with six spokes (*aras*), probably the other spokes are concealed. The supporter, perhaps made of wood, is shown supporting the hub of the wheel. The pots with pronounced and flaring mouth are mounted on the outer rim of the wheel with ropes at regular intervals. The position of the wheel and the direction of pots unmistakably indicate the rotary motion of the wheel, that too in the anti-clockwise direction.

As a potter's wheel continues to revolve from the force of the previous impulse, so also the wheel of pots circulates continuously with momentum gained by the human force or movement of the running water. The man who stands very close to it must be an operator. The presence of an animal (elephant?) to the right and the warrior with the prancing horse to the left cannot be satisfactorily explained. One noticeable absence in the panel is the horizontal wheel which is an important part of the 'Persian- wheel' mechanism. Anyway, this solitary piece of evidence would suffice to testify the existence of such indigenous devices in the northern villages in ancient India (Srinivasan, 1970, pp. 379-389). So it is a misnomer to brand '*araghaṭṭa*' as '*Persian- wheel*'. We may safely say that they represent pre-Persian wheel technology and operated on the water surface.

To conclude, on the basis of some literary and archaeological data, water-supply in the arid and scarcity areas in ancient India was doubtless derived from



Fig.6. Panel depicting warriors and the wheel of pots (jala- yantra- cakra) from Mandor (11th century A.D.) (photo courtesy: ASI, New Delhi)

water-lifting machines. But they have survived the ravages of time despite the emergence of modern discoveries and new techniques. Particularly , the two old inventions, the buckets and levers and the wheel of pots have neither been revised nor discarded nor replaced by new ones. This is because of the fact that all these devices employed for raising water are simple, economical and effective. It is therefore, reasonable to conclude that the invention of these devices not only served to enhance the technical ability of the inventors, but also paved the way for a more intensive cultivation than the single annual crop.

Notes

1. *Eight leaves of the treatise on water by sage Garga are even now preserved in the Library of Nepal Darbar. This manuscript is dated A.D. 1070 (Central Board of Irrigation and Power, Leaflet No. 7, 1953, p. 5).*
2. *One among the thirty-two karṇas or departments, according to the Lekhapaddhati, Gaekward Oriental Series No.XXI, pp.97-128 (Glossary), see also Sircar, 1966; Murari K, pp.194-95.*
3. *The Perumbāṇāruppaḍai, one of the idylls of the Paṭṭupāṭṭu refers to a large vessel, sāl for drawing water. The word sāl also stands for a unit of cultivation measured by the quantity of water irrigated by it. In the northern part of India leather buckets were used to draw water from wells and canals. This is evidenced by a Partabgarh inscription of the Gurjāra-Pratihāra period (A.D. 946). The kosavāhe is applied to as much land as could be irrigated by one kosa or leather bucket (EI. XIV. p.176).*

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Roads And River Transportation

K.V. RAMAN

Transportation is the act of moving of people or goods from one place to another. It is one of the most important necessities of trade without which there could be no towns and cities. Therefore, transportation becomes one of the basic instruments of civilization. Long routes were discovered in the course of immigrations and substantiated with the emergence of active trade.

Ancient cities grew along the river banks. Linking of these cities led to new routes — both across rivers and through lands. Thus many old routes are found on the banks of rivers.

The earliest evidence for wheeled vehicles is from the Near East - Southern Mesopotamia and datable to 4th millennium B.C. In India,the earliest evidences comes from the Harappan civilization (3rd millennium B.C.). These are the toy carts, which prove the existence of ox-drawn vehicles.

Indus Valley

The remarkable uniformity is the characteristic feature of the town-planning of the Indus. This is evident from the regularity with which the city of Mohenjo-daro is divided up - a regularity which is striking for an ancient city (Marshall). They interesected each other at right angles dividing the city into square or rectangular blocks.

Alignment

The streets of the Indus Cities—both wide and narrow are aligned, as regularly as possible, instead of winding as was usual in very early cities. The alignment was done by simple methods, with no evidence of instruments. This led to slight divergences — especially in streets that were supposed to be parallel. However, on the whole, especially in shorter distances, the alignment can be termed as accurate (Marshall).

Orientation

The main streets of the city of Mohenjo-daro are oriented to the points of the compass, with the houses and public buildings corresponding with the streets, in their orientation.

Size

The size of the streets varied. The broadest streets were over 30 ft. wide and the streets in the less important parts of the city measured only around 13 ft.

Lanes

Lanes were mainly used by people to pass from one street to another. The lanes also served to divide one block from another. These lanes varied from 3′8" to 7′ in width.

Barred streets

Some streets in Mohenjo-Daro have thin walls across them, thus barring them entirely.

Rounded street corners

Many of the corners of the streets were slightly rounded as if they had been worn by pack animals rubbing against them (Marshall). In two cases, the corners have been deliberately trimmed, and subsequently rubbed smooth by traffic. This was done so that loads might not be dislodged.

The streets of Mohenjodaro were unpaved, but terracotta nodules seem to have been used in Kalibangan — especially for metalling the road surfaces in upper levels. Streets in Kalibangan also ran along the cardinal directions.

Carts and cattle were used as means of transport — over land routes. This is evidenced by the finding of terracotta models of bullock carts. Further, cart-tracks were found on the roads of Harappan cities. Copper and bronze models of carts have been excavated from Harappa and Chanhudaro.

Dockyard at Lothal

So far there are only two pieces of evidences for water transport - one on a seal and another a potsherd. This is a trapezoidal brick structure measuring 710′ × 124′. It is rivetted on all four sides with a continuous dry masonry burnt-brick wall, 4 courses wide, which at its greatest extant depth reaches to 14 ft, (but might have been originally much higher). The structure was stratigraphically connected to the old river-bed of Sabarmati.

The discovery of five anchor-stones in the basin of the dock, the absolute verticality of the walls of the embankment without any provision for reaching the water-level by means of a ramp or flight of steps and the extraordinary salinity of the silt inside the dock indicate that the structure was designed to serve as a dock.

Towards the southern end of the eastern embankment there is a broad and relatively shallow gap. This has been supposed to be the inlet channel of the dock. Leading from the southern wall is a narrow brick water passage, said to have functioned as a spill channel, when fitted with a sluice-gate.

According to S.R.Rao, the dock has been used in two stages:

i) Stage I = It was designed to sluice ships 18-20 metres long and 4-6 metres wide.
At least two ships could simultaneously pass and enter easily.

ii) Stage II = The inlet channel was too shallow and narrow to accommodate large ships and only flat bottoms could enter.

Vedic Age

The Vedic Indians who lived in the mid 2nd millennium B.C. followed a rural economy where cattle was the dominant feature. The vedic literature implies the movement of these tribes towards the East with their cattle, driving in carts and chariots.

As pointed out by M. Sparebrooke, "on the Indian continent, famous for its cherishing long unbroken traditions, the chariot figured prominently throughout its early history, and even in the present day India, reminiscences of the ancient Vedic battle chariot have been preserved.

The huge ceremonial vehicles in which a God is pulled through the streets on festive occasions are still called 'Chariot' and frequently horses and charioteers sculptured, or of wood are represented on it."

In the Vedic period, chariots are mentioned in the texts frequently. No material evidence of any mode of transport, especially vehicles have been found possibly because like ancient temples they were made probably mostly of perishable materials such as bamboo, wood and cloth, and were, probably never buried. The chariot in the Vedic Index is described as a light vehicle with two spoked wheels, drawn by two horses, sometimes four.

The material of the hymn collection, implies a prior knowledge of the chariot. The chariot race is frequently mentioned in the *Ṛgveda* and was often used to propitiate the Gods. These races were attached with religious significance.

From the time of the *Ṛgveda*, the greatness of the chariots is praised and Soma is compared to it. The chariots driven by the Vedic deities also attained a divinity.

The *Brāhmaṇas* express the efficacy of the chariot by identifying it with Indra's *Vajra*. It played an important role during the performances of ceremonies, — like the *Vājpeya Rājasūya* and *Aśvameda* sacrifices.

Epic Age

In ancient India, the means of communication was through messengers and there existed numerous roads of varying types, eg. *Rājamārga*. Many roads connecting the important cities of *Āryāvarta* existed. One such example was the *Tāmasamārga* a highway which Rama took to reach Sringaverapure. According to North western recension of the *Rāmāyaṇa* a good road was auspicious and safe and further afforded fruits and water for the traveller (Guruge). The N.W recension of the *Rāmāyaṇa* gives a detailed account of how a road is built. Jungles were cleared and levelled to make way for paths and roads. Pits and low level areas were filled.

Mounds and hillocks were razed. Fords were constructed to cross rivers. Since most of the old routes were built along the river banks, the traveller had a constant supply of water. The roads were not paved.

Bridges also seem to have been used as gleaned from the word *Setubandhana*, Rama's bridge to Lanka.

Beasts of burden are also frequently alluded to in the *Rāmāyaṇa*. According to P.C. Dharma, 'the transport of commercial goods was effected by packhorses and pack bulls' (as cited by Guruge).

Elephants walked majestically on the royal roads. These were probably used to bear royal persons on ceremonial occasions.

Vahana is another term frequently used. *Śivikā* or palanquins were also a popular mode of transport. This is referred to by Daśaratha as a means of transport for desert and forest. Sita is said to have been brought in a palanquin, after the war. The bow of *Janaka*, the *Rudradhanus*, is said to have been brought in an iron wagon with 8 wheels drawn by 800 men.

Chariots were another important mode of conveyance. It was probably used by the more effluent people in the kingdom. Chariots of various types are mentioned including the ones made of precious metal. *Vaiyaghra* meant one covered with tiger skins while *Pāṇḍukambalī* were covered with white woollen blankets. *Akṣa* (axle), *yuga* (yoke), *nidha* or *bandhura* (seat) and *kubara* (wooden frame) are the various components of a chariot that can be gleaned from the epic. These were usually drawn by horses. *Brahmaratha* was a special type of chariot used by the *Brāhmanas* of the Epic age.

The *Bhagavatam* says that Lord Krisna carried away Ruksminī in his swift moving chariot.

The *Mahābhārata* mentions great charioteers in the battle fields of Kuruksetra (Krisna as Arjuna's charioteer). Each chariot had flags atop, according to his choice (eg. *Hanumadhvaja* of Arjuna).

Rivers were crossed by means of boats. Guha had the reputation of being an excellent boatman. Bharata's party was supplied with 500 boats with the auspicious '*Svastikā*' symbol marked on them (Guruge). The tale of Rsyasrnga refers to a ferry like a "floating island", used to bring him to the kingdom.

Buddhist Period

According to A.L. Basham, by the time of Buddha, trade routes covered most of North India, and the Mauryan times saw further improvement and expansion. "Among the chief of the routes was the one which ran from the R. Ganges to Tāmralipti (Tamluk), not far from Calcutta up the river to the old city of Campa and thence through Pataliputra and Varanasi to Kausambi, whence a branch went to the part of Bṛgukaccha or the mouth of the Narmada by way of Vidiśā and Ujjaini (Madhya Pradesh)". Kauśāmbī was an important city even during the time of the Buddha and from there a trunk road passed along the south bank of the Yamuna to Mathura from which a branch crossed the modern Rajasthan and Thar desert to the Port of Patala near the mouth of the river Indus. He also points out the roads

connecting North Western India. "The main route passed through modern Delhi (ancient Indraprastha) and crossed the five rivers of the Punjab by way of Takṣaśīlā whence is continued upto Kabul Valley into Central Asia. The main route went from Ujjain to the city of Prathiṣtāna (Paithan in Maharashtra) in the Deccan, the capital of the Satavahana empire around the beginning of the Christian era. It then passed across into the Deccan plateau to the lower Krisnā and went into the great cities of Kāñci and Madurai."

The Buddha during the course of his travels, as a homeless ascetic, visited many places, including Rājagṛha and Uruvilva near Gaya. After his enlightenment he gave his first sermon at Sarnath. For 45 years he preached to the people of Oudh, Bihar and adjoining territories and finally died at Kuśinagara—now in U.P. This constant movement may imply a good network of roads.

Sanskrit Texts

Pāṇini attests to the existence of an over-land trade-route. He speaks of travellers going by *Uttarāpatha* and of goods gathered by that route. Pāṇini and Patañjali mention chief cities like Bālhika, Kapiśi, Puskalavatī, Masakavaṭī, Takṣaśilā, Sakala, Hastināpur, Kauśāmbī, Kāśī and Pāṭaliputra. Takṣaśīlā, by virtue of her strategic geographical position as well as her status as the capital city of Gandhara, played a leading role in the inland and foreign trade of ancient India (Ray and Sen).

Patanjāli indicates that the Grand Trunk Road of those days connected the two cities of Kauśāmbī and Varanasi, by mentioning the formations Niṣ Kauśāmbī and Nir Varanasi. He also states that Saketa and Pataliputra lay on the same road. Though Patañjali (5th-4th cent. B.C.) and Pāṇini vary on the cities which form the beginning of the road, (Patañjali-Saketa (Ayodhya) and Kāśika-Kauśāmbī), Pataliputra remains the final destination.

Mauryan Period

During the Mauryan period, a fairly extensive network of communication in different regions of the empire was established. Extensive roads were built and special trade routes established between the capitals of various states. The most famous of these roads were the Northern (*Uttarāpatha*) and Southern (*Dhakṣiṇāpatha*) which stretched all the way from North Western frontier to Pāṭaliputra and then still further east. The existence of roads from the Epic age (or immediately after) is also attested by Greek records especially that of Megasthenes who refers to the Royal Road (from North Western Frontier to Pāṭaliputra) as the road existing in earlier times, and which was 10,000 stadia in length. This was probably the road, Megasthenes himself took on his *enroute* to the Mauryan court.

This road is said to have been constructed in he following stages

i) Peukelàotis to Taxila (*sans Puṣkalavathi*)

ii) Taxila across Indus to Hydaspes (Jhelum)

iii) From Hydaspes to Hyphasis (Beas) near where Alexander erected his altars

iv) From Hyphasis to Hesidrus (Sutlej)

v) From Hesidrus to Iomanes (Jamuna)
vi) From Iomanes to Gaṅgā (via Hastināpur)
vii) From river Gaṅgā to Rodopha possibly Dabhai near Anupshalias
viii) From Rodopha to Kalinapaxa (Kāṇyakhupja or Kanauj)
ix) From Kanauj to Prayāg
x) From Prayāg to Pāṭaliputra
xi) From Pāṭaliputra to the mouth of Ganga probably Tāmaralipti

The distances were supposed to have been measured out by Baeto and Diognetus, two survey officers of Alexander upto Hyphasis (Beas).

From Hyphasis to river Ganga, the distance was measured out by Megasthenes and other Greek writers for Selukus Nikator.

Megasthenes further mentions that the Mauryas "construct roads and at every ten stadia set up a pillar to show the by-roads and distances". Pliny also quotes Megesthenes in that the road was in charge of officers of the public works department. They were responsible for its upkeep - any repairs and the maintenance/erection of signposts.

The *Indika* also mentions that whenever the king set out on hunting, the roads were blocked by ropes and cleared of obstacles and dangerous persons. Dikshitar takes it as a reference to the *Rāja-Mārga* or the Royal road of Kauṭilya. The latter also states that the royal road was well guarded on both sides and cleared of armed persons, beggars and the crippled.

Numerous fragmentary and complete examples of terracota toy cart wheels found during various periods give some idea of wheeled vehicles such as carts. They were presumably wooden carts - used mainly for carrying good and passengers.

Terracotta wheels have been excavated from the early levels (800-200 B.C.) Period I of Varanasi. These wheels are plain without spokes and hub, but they possess a hole in the centre to take the axle.

A few model carts also constitute evidence for the use of simple carts. These are also found in the Ganga valley and can be dated to 3rd and 2nd centuries B.C.

A simple type in frame, made of tortoise shell has been found from Campa. "It possesses a body frame long and rectangular and at the yoke-end curving in triangular-cut sharpness. It has a horizontal perforation at the rear end for the axle and a vertical hole at the yoke-end for animals" (Margabhandu).

The wheels are solid, without spokes. The details of the toy-cart and measurements reveal its proportionate design to mathematical precision.

Indika also gives many details regarding the breeding and training given to horses and other animals. Megesthenes mentions divisions of military officers who directed military affairs.

The vast empire maintained a highly organized army and bureaucracy - army of chariots, elephants, cavalry and infantry. It had eight thousand chariots and thirty thousand horsemen which presuppose the existence of good roads for the chariots to travel. The highly organized military administration had six special Boards to

look after six departments each one for admiralty, transport, cavalry,etc. Similarly, the well organized bureaucracy looked after accurate land survey and measurements and the maintenance of the roads. Megestheses mentions that there was a special officer, superintendent of bullock cart trains used for transporting the war equipments, food for the soldiers and other requisites.

The commissariat is mentioned by Kauṭilya. Their work was the examination of roads, bridges, wells, rivers, carrying machines, weapons, armours, provisions, etc.

There was a division one each for the horse, the war-chariots and the elephants. The chariots were drawn in the march by oxen, but the horses were led along by halter so that their legs may not be galled and inflamed by drawing chariots. (Dikshitar)

Kauṭilya also mentions this road, but describes it as the trade route (*Vanikpatha*). According to Kauṭilya, the *Dakṣiṇāpatha* was more profitable as it led to places producing valuable commodities like diamonds, gems, pearls, and gold.

According to a Pillar edict of Aśoka, at intervals of 8 *Kos* the roads were marked by rest-houses and wells. The Aśokan edicts also mention the improvements made in the communication by planting trees along the roads to provide shade. To implement his reforms, he appointed a new class of officers - the *Dharmamahāmātras*.

Water Transport

Apart from overland trade, river and sea-routes also came to be used extensively. Source materials tell us of Indian merchants undertaking dangerous sea voyages that lasted for as long as six months. Vessels set out for Śrīlaṅkā, Burma and Arabia. Many Indians were also despatched to the Hellenistic countries. Spices precious stones, ivory objects and rare kinds of woods were traded.

According to Strabo, the River Oxus, in the time of Alexander was quite navigable, so that goods from India were carried down the river to the Caspian sea on their way to the West.

According to the Buddhist texts, an important route led south-west from Sāvatthi (Srāvasti) to Patiṭṭhāna, (Prathiṣṭāna) with six halts and frequent crossing of rivers. The *Vinaya* texts mention boats going up the Ganges to Sahajati and up the Yamuna to Kauśāmbī. According to the *Jātaka* tales, there were no bridges, but only forting places and ferries for crossing rivers.

Waterway was considered more profitable since it required less labour and hence less cost. This is known through Kauṭilya's observations. According to him,

i) Waterways cannot be used in all seasons.

ii) It is also risky without adequate remedies.

He further alludes to the river transport as the third waterway - the first two being i) along the coast, ii) midway along the ocean. Kauṭilya criticized a river fort as he felt it could be crossed. This fear probably stemmed from Alexander's invasion and

the defeat of Porus, through the former's powerful "bridges of boats" with which he crossed rivers.

The *Jātakas* mention that boats went west via Pāṭaliputra, Prayāga and Varanasi.

According to *Mahāvaṃsa*, Mahendra and Saṅghamitrā started their voyage to Ceylon through the boats across the Ganges from Pāṭaliputra.

The *Periplus* saw large Indian vessels in the Malabar coast that were known as *Sangara*, root of the word *'Sangada'*. In the first century A.D. the Egyptian traders used to send the ships to India and Indian merchants according to *Periplus* took up permanent residence in the island of Dioscorides (Socotra).

Pre-Christian Era - Sunga, *Kṣatrapa-Śātavāhana periods*

A network of roads developed early in the Christian era from this old route linking all the important cities of the Peninsula. Terracotta wheels without spokes and hub continued to be in use as is testified from the findings from stratified deposits at Varanasi.

A cart frame has been found depicted in a terracotta tablet known from Bangarh datable to about 2nd century B.C. This cart frame has a curved tip. The frame is of horizontal bamboo posts. It possesses a central axle evenly spaced for balance.

In the latter part of the 2nd century B.C. some changes occur in the technological features, Broader frames, thicker yokes and refined cart wheels seem to develop during this period. There is more variety in the treatment of outer frames which indicates the sophistication of its use, and its growing popularity in the urban centres.

Two important types are found:

1) Cart-frames depicting features like axle, pole and wheels. Example is a specimen from Atranjikhera datable to the second half of 2nd century B.C. It is a typical cart frame drawn by single or two bullocks - possibly a popular mode of transport during the period.

2) The second type depicts the animals in front with an open back, and passengers seated inside the vehicle. This type seems to have been popular at Kauśāmbī, which has yielded one of the best specimens carrying four men and two women (Margabhandhu).

The earlier specimens datable to 2nd and 1st century B.C. are more ornate while those of latter times (datable upto 2nd century A.D.) are crude. But these seem to be larger vehicles to accommodate more passengers.

One T.C. Plaque from Pāṭaliputra has a warrior aiming bow and arrow. A charioteer holds the animals. The scene depicts the wheel in motion. The ovaloid feature indicates the fast rotating wheel. The entire plaque is a unique representation interpreted as Lord Sūrya. A technologically similar model from Kauśāmbī (in conventional representation) has been found. These are probably datable to 1st century B.C.

Toy models from Brahamapuri, Carsada, Rairh, Raṅgmahal, Sambhar and Taxila are very similar to modern types. These are available in copper bronze and

terracotta. The types consist of simple carts (*ekkā*), bullock carts, horse-drawn chariots, light racing chariot, etc. These have transverse holes for axle under-neath the body and another hole for the pole in front. The wheels show heavy and clearly defined hubs and fellies (Margabhandhu).

Some of the examples have circular projections at the rear with 11 bars which not only kept the weight balanced but also provided more space for sitting and luggage. Brahmapuri has yielded evidence of covered wagons made of copper.

A two-wheeled vehicle has been recorded from Sirkap(c100 A.D) which according to Marshall "appeared to be a sort of light racing chariot". Similar transport vehicles was also represented at Brahmapuri (Maharashtra).

Literary references testify that merchants and traders moved along in caravans with their commodities so as to avoid being attacked.

Spoked wheels with one hub-on the outer side come into existence around the beginning of the Christian era.

Availability of bridles, checkbars and stirrups suggest that horse-drawn chariots were common during this period.

The chief material evidence can be divided into

1) Rock paintings
2) Parts of bridle-equipment
3) Toy vehicles
4) Sculptured representation of temple-reliefs. A grave at Nagpur has yielded an early pair of stirrups and a snaffle. This is similar to a specimen from Taxila and has been suggested closer to 3rd and 4th centuries B.C.

A number of seals depict chariots. On a seal from Jhusi (2nd century B.C), the hindlegs of horses and a chariot-wheel are visible with 2 persons sitting in it.

From a plaque from Bhita (Varanasi dist.) dated 2nd century B.C. a chariot is discernable.

Stirrup bits at Sambhar (200 B.C) made of iron has been identified as a child's stirrup. Chariots are also seen depicted on the stupa gateways of Sāñcī. The sculptured panels are normally ascribed to 1st century A.D.

Sāñcī Stupa I: Front of Southern gateway - middle architrave - Aśoka's visit to the stupa of Rāmagrāma. The chariot is drawn by horses with complete bridle equipment. The wheel has about 14 spokes, elongated in a diamond shape. It depicts infantry, cavalry, elephantry and chariots.

Stupa-I

Northern pillar of Eastern gateway shows King Śuddhodhana leaving his town in a chariot accompanied by an elephant with a rider. The Sātavāhana times indulged in great maritime activity. This is evidenced by the Andhra coinage which frequently feature a ship with two masts.

Gupta Period

Internal and foreign trade expanded to a remarkable degree, during this period (4th-6th century A.D.). Many uninhabited regions had been settled, transport was better organized and trade routes more closely linked. The economic specialization of various areas and zones made exchange of commodities essential. Under the Guptas the state had devoted particular attention to the construction of roads and communications. Yet the exchange between various parts of the country was still of limited nature. Roads were not always suitable for long journeys and traders encountered a good many problems. Rivers were now being made much fuller use of. This applied in particular to the Ganges and the Indus.

The Ganges Valley was the principal trade area from which branched off trade routes leading to many parts of the country. The main trade centres in that area were Bṛhukkaccha (Barygaz) in the west, Patiālā in the Indus delta, Puṣkalavatī in the North-West and Tāmralipti (modern Tamluk) in the east. In Eastern India, Varanasi, Kauśāmbī and Pāṭaliputra and Ujjain were well known for their high quality wares.

Fehien's travel to the various Buddhist places and his account attest to existence of good roads and transport system during the Gupta period. In the course of his travel he visited Vaiśākha, Napikā, Kapilavastu, Ramagrāma, Kusinagara, Vaiśālī, Pāṭaliputra, Rājagrha, Gayā, Vārānasi, Kauśāmbī, Campā. He further states that the roads were safe, whereas two centuries later Hieun Tsang was twice assaulted.

Post-Gupta

A host of traders and merchants carried the products of their various industries from one end of the country to the other by means of boats and bullock-carts.

Traders and merchants of various descriptions and their fabulous wealth are frequently referred to in books and inscriptions (R.C. Majumdar).

Trade and industry were well developed and organised. The institution called *Śreṇī* was a corporation of men following the same trade, occupation or craft and resembled the guides of medieval Europe. Almost every industry had its guild which laid down rules and regulations as a definite constitution. They maintained armies for the use of which wide roads were maintained.

Hieun Tsang gives information about the roads during the reign of Harsha Vardhana. He says that the roads were not safe. The Chinese traveller moved from one Buddhist place to another, visited even Kāñcipura and has left behind graphic details of the prevailing conditions.

Land pilots were supposed to have been the most important persons in a desert camp. The traders and their entourage travelled by nights, and rested by day. The route was chalked out by the land pilot by constantly watching the stars.

The paintings of Ajanta give ample proof of shipping activities. One of the paintings shows a vessel with high stern and three oblong sails attached to three upright masts. The vessel is of the *agramandira* type as defined in the *Yuktikalpataru*. This work can be dated to 11th century A.D. and gives graphic information on ship building in ancient India. The fact that the painting (dated

earlier than the work) depicts a vessels that corresponds to a later description shows that the models did not undergo much change. Two types of ships are also mentioned, *Sāmānya* for inland traffic and *Viśeṣa* for sea traffic. Each is in turn divided into various categories.

Various classifications of colours, wood, and even decorations also seem to have dominated in the ancient days. Sometimes, hundreds of bullock-carts gathering together and forming a caravan traversed from one end of the country to the other and occasionally we hear of bands of volunteer police being hired to protect the merchandise on the way from thieves and robbers. By means of rivers, canals and highways, the commodities were despatched to the ports and harbours with a view to their export to foreign countries in sea-going vessels.

Tamil Nadu Transport

In South India in the Saṅgam Age, trade and transport was by means of vehicles. Puram literature. (c 100 B.C - 100 A.D) speaks about the use of various vehicles by the salt merchants to transport their merchandise from one place to another. The work goes on to mention that women of the *Parambu Malai* region stood on mounds to count the number of salt vehicles passing through their village.

The *Śilappadikāram* (5th-6th cent. A.D) says that Madavi went in a vehicle called *Vaiyam - also* called *Koṭṭapaṇḍi* and *Koodarapandi*. *Cinthāmaṇi*, a medieval Tamil work says that vehicles (*vandi*) were earlier called *paṇḍis*. But there is no information regarding the decorations given to a means of transport.

Chariots

The *Aham* and *Puram* literature give ample evidence of chariots - as an important means of transport, and that it was drawn by horses. *Aham* (36:13) stresses the importance of chariots. The line also reveals that horses were called *puravigal.*

The *Sirupānārrupaḍai* explains how the chariots were made. In a beautiful verse, the wheel of the chariot is compared to the moon on a Full Moon Day. The spokes that connect the outer layer of the wheel to the inner axle are compared to the rays of the moon. The "*palagaigal*" that were attached to the inner layer of the chariot gave it a shine that matched the brilliance of the moon.

The *Purananuru* (verse 290: 4-5) extolls the exquisite workmanship of the blacksmith, that was clearly revealed in the making of chariots, that moved so easily and smoothly. The chariots were drawn by attractive horses or bulls with a graceful gait.

The *Sirupāṇārrupaḍai* terms the movement of vehicles in a single row as '*olugai*'. The work also cites the merchants ingenious method of making monkeys follow them at the back for the sake of safety.

The *Purāṇānuru* (32:8) wonders if the wheel used by the potter to make his pottery was called *ther-kāl* since it resembled the wheel of the chariot(*ther*). Another such verse indicates the condition of the streets from the fact that clouds of dusts rose when the chariots passed by. Streets with curves are also mentioned.

Boats

According to Paranar (*Puram* 343:5-6) the gifts of gold from foreign countries brought in by ships were carried ashore with the help of small boats. The shallow sea-ports where ships could not ply hummed with the steady movement of small boats.

The *Paṭṭinapālai* compares the row of boats in the back waters of Poompuhar to the rows of horses kept in their stables. It also mentions that the horses were imported from across the seas to Tamil Nadu. The work also informs us that the boats that sold paddy and brought back salt were called *pakri.*

Ambi was the name of a boat which was used for fishing. According to this verse (*Puram* 261) these boats called *ambi* looked like residential structures on account of the mounds of paddy that were kept in.

We also learn about the existence of another boat called *thinuli* from the Puram verse of Erumai Veliyanar.

Vangam was the term used to indicate big boats that plied on the sea. These boats which made loud noise were used to transport rare goods across the rivers and seas.

While describing the various articles pouring into Poompuhar, the *Paṭṭinapālai* mentions the gems and gold from Northern mountains, the Sandal from Western mountain, Pearls from Southern sea, products of Ganga and Kaveri and Kazhagaaṃ (i.e.) Malaya Coast. Such a great magnitude of trade would have been possible only if a good transport network existed. Merchants took great part in developing Poompuhar as a great national and international port. It was called as *Kaberis-Emporion* by the Roman writers. It was well connected to all important trade centres and capitals in the hinterland by roads.

The *Periplus of the Erthrean sea,* mentions 3 kinds of crafts

1) light coasting boats for local traffic,
2) larger vessels of more complicated structure and greater capacity, and
3) big ocean going vessels (K.A.N. Shastri)

The *Paṭṭinapālai* also compares the big ships that were moored in harbours to restless elephants. *Manimekalai* compares Udayakumar to a ship caught in a storm.

Maritime trade remained an important activity from the ancient Tamil period - through the ages. A direct sea route to China became a frequent passage around the 7th century A.D.

Māmallapuram, Kāveripoompaṭṭinam, Saliyur and Korkai on the east coast and Quilon and Muziri on the West were great emporiums frequented by traders of other countries.

In the 9th century A.D an extensive maritime and commercial activity had developed including most countries of South Asia including the Abassid Khalifat at Baghdad.

The *Nānādeśa-Tiśaiyāyirattu Ainūrruvar* were a celebrated guild. They were a powerful autonomous corporation of merchants whose activities apparently took

no account of the political boundaries and visited all countries in the course of their trade (K.A.N. Shastri). Their Tamil inscription is found in Sumatra.

Missions and envoys were sent to China in the early part of 11th century A.D. during the reigns of Rajaraja Cola I and his successors.

Cola Transport

The Cola inscriptions mention roads while describing boundaries of gifted land. There were two types of roads.

i) *Vali* - only for foot travellers

ii) *Peru-Vali* - trunk roads leading to various divisions of the Kingdom.

Examples are *Vadugapperuvali* or Andhrapatha, *Kongupperuvali* Road (leading to Salem, Coimbatore); the *Tanjavurpperuvaḷi* mentioned in an inscription from Aduturai (363 of 1907).

Another inscription from Tanjore (203 of 1908) records the road leading to Kalyāṇapuram (capital of the Western Cālukyas).

The existence of great roads like the ones mentioned testify the use of wheeled vehicles, and constant movement from one place to another.One such road is mentioned as having been 2 *kol*(24 ft)

A milestone or an indicator mentioning directions belonging to 13th century has been discovered in North Arcot District.



Fig.1. A tenth century road sign mentioning it as the Rajkeśarī Peruvali (High road at Sundaikkaimuthur, Dt. Coimbatore, Tamilnadu)



Fig.2. A thirteenth century road sign mentioning it as the Vikrama, Pandyan Street, 6th Ward at Tiruvannamalai, N.Arcot district, Tamil Nadu. The Pandyan royal emblem (double fish and hook) are inscribed.

North India between 700 - 1200 A.D.

By the 7th century A.D North India was fully connected by great roads. Religious travel or pilgrimages became a way of life and there was constant movement - both by the Buddhists and the Hindus - to the various sacred places.

The great University of Nālandā also attracted students from various parts of the world and great travel facilities were required. Various works mention caravan journeys undertaken by merchants. They include *Bhavisayattakaha*, *Samaraiccakahā* and *Triṣaṣṭiśalākāpuruṣacarita*.

As pointed out by Lallanji Gopal *Medatithi* clearly refers to carts (*gantri*) drawn by bullocks, mules, buffaloes and other animals. The *Upamitibhāvaprapañcakathā*

mentions that hiring caravans of large carts and animals (mules) for drawing them, yielded high income.

Raṭhya is a street through which carriages passed and Laghurathya meant a small carriage street. The *Samarāṅganasūtradhāra* mentions many kinds of roads.

Facilities for travellers included water reservoirs. This information can be gleaned through *Tilakamañjarī*, which also states that the king appointed officers to provide food, drink, beds and medicine in charitable houses. Such houses (*Sattragara*) are also mentioned in the *Prabandha cintāmaṇi*.

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Jewellery - Inlay Work And Studding Of Gems

M.L. NIGAM

Love for Beauty is an inherent quality in all human beings. It is this aesthetic impulse which prompts an individual to create, possess and enjoy all that is beautiful. Jewellery is, no doubt, an aid to personal beauty and this is probably the reason that the art of jewellery has all through been associated with the development of human civilizations.Besides,jewellery has also been considered as an insignia of personal status. Even the icons of gods and goddesses are provided with numerous jewels and jewellery. With ancient pastoral society of India, the herds of cows, large stables of horses, elephants and precious gems were recognised as the four main treasures. Hence, the possession of costly gems and jewellery and its luxurious use on festive and ceremonial occasions in India have been associated with the rank and status of its owner in the society.

There are other reasons too for giving a boost to the craft of jewellery in ancient India. The medicinal qualities of various precious stones and metals were found conducive to human health. Similarly, the common astrological belief in India that every planet has its own gem and the wearing of that gem will pacify the particular planet probably augmented the use of gems and jewellery amongst the opulent class of Indian society.

Thus, the wearing of Nine Gems (*Nava Ratna*) viz; diamond (*Hīrā*), Ruby (*Mānikya*), Cat's eye (*Vaiduryam*), Pearl (*Muktā*), Zircon (*Gomedha*), Coral (*Mūṅgā*), Emerald (*Markatam*), Topas (*Pukharāja*) and Sappire (*Nīlam*) had attained astrological sanction amongst the Indians.

Besides, the possession of gems and jewellery in ancient India was further inspired by an element of personal safety against future odds of poverty as well as natural mishaps in one's life. The gems and jewellery have always a re-sale value and the same can be converted into cash as per the need and wish of the owner. The malleable quality of the precious metals, like gold and silver, however, proved to be detrimental to the continuity of old forms. The frequent melting of old ornaments led to an extinction of ancient jewellery of India. However, the ornaments made of base metals have preserved the ancient forms of Indian jewellery. Today, it is difficult to get good specimens of old Indian jewellery except in temples of southern

India, wherein the temple-jewellery is still kept intact. Again, the treasure- troves and archaeological excavations have also occasionally brought to light some of the precious remains of ancient Indian jewellery which not only exhibit high excellence and perfection that the craft had attained but also throw adequate light on the economic prosperity. The old jewellery also throws light on social norms including the social customs and traits, motivations and behaviour, concepts and ideas and myth and philosophy of the people.

The art of jewellery in ancient India forms an interesting study. Both the archaeological and literary sources throw ample light on the subject, right from Indus Valley period to the beginning of British rule in India. A metallic figure of a dancing girl from Mohenjodaro would suggest the use of various ornaments, such as the necklaces, armlets, wristlets and bangles during the Indus Valley civilization. Ivory seems to have been the main medium for producing bangles and other ornaments at Mohenjodaro and Harappa. Further, the excavations at Mohenjodaro and Harappa have yielded a large variety of beads of numerous shapes and materials. Hence, the strung beads were worn as armlets, bracelets, necklaces and girdles during Indus Valley period. The beads of the precious metals, like gold and silver must have been scarcely used, as they are found in less quantity. The beads of semi-precious stones, like jadeite, carnelian, jasper, steatite, quartz, agate, onyx and black chert have been found in abundance. The beads of less costly material, such as the terracotta, shell, wood and clay must have been used by the poor people. The glass beads have also been found.

It is no less amazing to note the diversity of techniques applied in producing such a large variety of beads in ancient India. The beads are fashioned in cylindrical, globular, tubular, short barelled, rectangular, oval and semi-circular forms. Apart from the science of metallurgy, the people of Harappa and Mohenjodaro possessed a good knowledge of the use of various hard stones. It is somewhat difficult to imagine about the tools and technique employed to manufacture beads from such semi-precious stones, like the quartz and jadeite etc., which are harder than the steel. They probably practised the methods of rubbing and abrading the pebbles with particles and pieces of harder stones and bringing them to desired forms. Similarly, they might have used the drills and borers of quartz and other harder stones to carve out holes in the beads presenting lesser hardness. The technique of soldering the edges of two convex discs to produce double convex beads can also be noticed. At Harappa, the special type of beads were made by cementing two or more stones together. The steatite beads are sometime given special treatment of heating to whiten the surface. Such beads are termed as "burnt" steatite beads. There are painted steatite beads also. The fast colours were produced by applying mineral solutions and thereafter heating them under high temperature. The beads were also glazed and polished to present a glossy surface.

Archaeological data about the jewellery of early Vedic period is somewhat scanty. However, there are stray references, gleaned through the hymns, which provide a vague idea of the jewels and jewellery of ancient period. The *Vājasaneyī Saṃhitā* (XXX) and the *Taittirīya Brāhmaṇa* (III.4) do present an account of various arts and crafts, which include workers in gold and so also the profession of jewellery (Apte, 1965). Similarly, there are references in Vedic literature regarding

ornaments, such as the *Pra-varta* or ear-rings and a *niṣka*, probably a *kaṇṭhī* or a small necklace worn around the neck, jewels (*mani*) and conch-shells were also used as amulets during the period (Apte, 1965).

Ramesh Chunder Dutt has brought out numerous references from *Rgveda*, wherein certain names of ornaments are mentioned. Accordingly, the lighting ornaments of the Marutas are compared with jewellery (*Anji*), such as the necklaces (*Srak*), the crowns (*Sipra Hiraṇmayī*) (Dutt. 1893). The science of metallurgy had advanced considerably. A passage in the *Chāndogya Upaniṣad* specifies various metals. It reads, "As one binds gold by means of silver, and lead by means of tin, and iron by means of lead, and wood by means of iron, and also by means of leather" (Dutt, 1893).

It was during the rule of the Mauryas that India was, for the first time, brought under one political power. It added not only to the political stability of the country but also to increased resources, economic growth and an all-round prosperity of the people. This fact has very well been brought out by various foreign writers in their respective chronicles. Both Megasthenes and Nearchus speak eloquently about the love of Indians for ornate jewellery. They had appropriate ornaments made of silver, gold, pearls, gems and other precious stones to be worn on every part of the body. The *Jātakas* mention eighteen important handicrafts, including those of the workers in precious stones and jewellery. Strabo further testifies that the Indians indulge in jewellery (Cunningham, 1962). Although, there is not much archaeological evidence available at the moment to give further details about the concrete forms and character of the Mauryan jewellery, yet it may be inferred that the traditions of the Mauryan jewellery must have continued during the Sunga period also.

Early historic jewellery

The Buddhist monuments at Bharhut, Sāñci, Bodhgayā and Amarāvatī, which are attributed to the Sunga and Śātavāhana phase of Indian history, provide ample evidence on Indian jewellery through their intricate stone carvings. The jewellery, as noticed through the carvings of the figurative sculptures, is important for two significant reasons, viz; firstly the forms of jewellery have been continued throughout the ages with little or no change and secondly, the identification of various ornaments worn by the male and female figures at Bharhut can easily be made with the help of ancient literature of India. Another important fact which can be brought out by studying early sculptural art of India is that the trait of wearing beautiful jewellery was common with the male and female sections of the society. Further, the jewellery was worked in precious and semi- precious metals and the same was encrusted with the pearls and glittering gems for the royal use.

A careful scrutiny of the Suṅga and Śātvāhana art would reveal that a large variety of ornaments to be used on the head, ears, neck, arms, waist and feet had come in vogue. The forms, motifs and designs of ornaments were drawn either from Nature or the sectarian symbols. For example, the ear-rings are very often shaped like a full blown lotus flowers and petals. The numerous animal motifs, such as the snout of a crocodile, lion's head and coil of a serpent have been imitated to shape

the numerous ornaments of the Śātavāhana period. At Bharhut, the famous Buddhist symbol, *Tri-ratna*, is very often found depicted in the personal jewellery of male and female figures.

Again, the ornaments, like ear-rings, necklaces, armlets and bracelets, seem to have been commonly worn by both the male and female members of the society. However, the forehead ornaments, long necklaces, girdles and anklets were worn only by the fair sex. The males probably used an embroidered cloth, *saṣ* or *pataka* to tighten the waist. The nose-ring is probably a later addition to Indian jewellery.

Forehead ornament: The female sculptures from Bharhut are invariably shown wearing a star-shaped ornament just below the parting of the hair on the top of the forehead. The term, *Lalāṭīkā*, as used in ancient Sanskrit literature, has been interpreted as a jewelled ornament on the forehead (Sivaramamurti 1956). Similarly, the gem *Cūḍāmaṇi* or the *Makarika* (crocodile gem) are found adorning the foreheads of the female sculptures of Amaravati and Nagarjunakonda (Sivaramamurti, 1956).

Ear ornaments: Ear rings were used by men and women both. Sometimes, the ear-rings are shaped as *Tri-ratna* symbol. Even today, the Christians wear the cross as ornament. Cunningham has described a special type of ear-rings used at Bharhut, wherein the middle portion was formed of two spiral tubes and ending with a four petalled flower (Cunningham,1962). Agrawala has identified them with *Prakaravapra Kuṇḍalas*, as mentioned in the Virata Parva of *Mahābhārata* (Agrawala, 1965). The crescent- shaped kuṇḍalas (*mṛṣṭakuṇḍalas*), which find mention in the *Jātakas*, are found represented in Amaravati sculptures (Cunningham, 1962).

The actual specimens of this kind of *Kuṇḍalas* were excavated from Taxila by Marshall (Marshall, 1902-3). The *Vallikā*, as mentioned in the *Cullāvagga*, has been identified with modern *Ballikās* or *Bālā* (Sivaramamurti, 1956).

Necklaces or Kaṇṭha-bhuṣaṇa: The necklace seems to have been the most popular ornament amongst men and women in ancient India. The necklaces were made of gold, beads, pearls and other precious stones. Kauṭilya in his *Arthaśāstra* has mentioned a large variety of necklaces, including their characteristics and names (Shamasastry, 1923-24). The necklaces were generally composed of numerous strings, popularly, known as *Yaṣṭi* and the central part of it was adorned with a large gem, called *nāyakamani*. A necklace comprising of gold coins was named as *Niṣka*, which was also the name of a gold coin (Apte, 1965).

The necklaces used to be both, short and long. The short necklaces were known as *kaṇṭhī* or *kaṇṭha*, a name which is still retained in Indian vernacular. In the Bharhut sculptures, the short necklaces are broad and flat, going around the neck. They might have been made of plain gold. The other varieties of necklaces were probably made of gold beads, pearls and precious gems. The necklaces were made either of one string (*ekāvali*) or more than one string. If the central gem is large sized pearl, the necklace was called *śirsak*. A necklace composed of alternating pearls and gold globules was termed as *apavaritaka*. *Ratnāvali* was a variegated necklace composed of gems, pearls and gold globules (Kauṭilya's *Arthaśāstra*, Shamasastry, 1923-24).

Another notable variety of necklace used in Maurya and Sunga age is the *Phalakahāra* which comprised of three or five slab like gems, rectangular in shape and set at regular intervals of pearls. It consisted of numerous strings as noticed from the sculptures of Bharhut and Amaravati (Sivaramamurti, 1956).

Bracelets: The armlets or bracelets were commonly worn by men and women of the Sunga period. They seem to have been made of gold and encrusted with precious gems. The bracelets were known as *Valayas*. According to the *Gāthāsaptaśati*, the *valayas* were considered as a symbol of auspiciousness for the ladies whose husbands were alive. The bracelets seem to have been named after the material employed and sometimes even after the workmanship. For example, the *Ratnavalayas* (*Mūdrārākṣasa*, Act IV, 5 p. 192) were the bracelets set with precious stones and cerals, the *Śaṅkhavalayas* were made of conch and the *Jalavalaya* (*Gāthāsaptaśati, I,* 80) were the bracelets showing perforated workmanship. The bracelets made of ivory were also in vogue. The most elaborate bracelets, as worn by the Yaksa, Yaksis and Naga figures at Bharhut, consist of spirals of ten coils each, with a jewelled plate on the outside of the wrist and on the inside a curious arrangement of four perpendicular wires attached to a loop, for keeping the spiral closed (Cunningham, 1962).

Like bracelets, the armlets were also known as *Valayas* due to their ring-like shape. The various shapes, based on the creeper and *makara* motifs, of armlet are mentioned in ancient Sanskrit literature (Sivaramamurti, 1956).

Girdles: There are numerous references to female girdles in early Sanskrit and Pali literature. The various names of female girdles seem to have been based on the number of strands in the ornament or the tinkling sound produced at the time of movement. The names, such as *Mekhalā, Kāñci, Saptakī, Rasanā* and *Sārasanā*, which are found mentioned in *Amarakośa*, are said to have signified the number of strands composing the girdle (Sivaramamurti, 1956). For instance, the term, "*Saptakī*" denotes a girdle with seven strings. "*Rasanā*" is probably the tinkling girdle with small bells suspended downwards. Sivaramamurti believes that the *Rasanā* or *Rasanākalapa* probably resembled a *mekhalā* but was fashioned like a cord or chain with numerous links composing it (Sivaramamurti, 1956). Similarly, the names *Kāñci* or *Kakṣa*, as Cunningham suggests, denote the specific girdles composed of brilliant red seeds of *Guñja* or *Abrus Precatorious* (Cunningham, 1962). The same scholar, on the basis of early Buddhist literature, takes the term *Mekhalā* as being "set with gems in newly burnished gold and silver" (Cunningham, 1962). The other names of girdles, such as the *Maddavīna, Kalābuka, Muraj* and *Deddubhaka* had their special characteristic qualities (Cunningham, 1962). The *Maddavīna* type of girdle had a rich, jewelled border. The *Kalābuka* was composed of many strips plaited together. The *Muraj* had drum-shaped knobs and the *Deddubhaka* had knobs in the form of a water snake.

Initially, the girdles seem to have been composed of beads, including those of gold and silver. The same might have been followed by chains of gold and silver with jingling bells, specially used by the dancing girls. This is how, as Cunningham takes it, the lady's girdle assured the elaborate and costly form of five, six and seven strings of gold beads (Cunningham, 1962). These girdles are found worn by the

various female figures of the Bharhut stupa. The most elaborate girdle, worn by the goddess, Sirima, represents similar motif and design in construction.

Anklets- Anklets were popularly worn by the ladies of the Sunga and Śātavāhana periods. The most common variety appears to be formed of spiral coils,piled one over the other (Cunningham 1962). The various names, such as *Manjīra Tulākoti, Nūpura, Pādangada, Haṃsaka* and *Pālipada* in Sanskrit and Pali languages would suggest a large variety of anklets in ancient India (Sivaramamurti,1956). However, the popular form of anklets noticed at Bharhut can be identified with the ancient term, *Manjīra,* which are supposed to resemble the coiled strings of the churning stick (Sivaramamurti, 1956). Sometimes, the anklets were embedded with small bells, *Kinkinīs* to produce the jingling sound. In the temptation of the Buddha, some of the dancing Apsaras are said to have, "tinkled the bells on their feet" (Cunningham, 1962).

Finger Rings: The Finger rings or *Aṅguliyaka* are found worn by the female figures at Bharhut. However, the same are not to be noticed at Amaravati in its earlier phase.The finger rings appear at Amaravati only during the 3rd century, A.D. (Sivaramamurti, 1956).

The foregoing description of Indian jewellery would reveal that the Indians, both male and female, had great love for ornaments right from the Indus Valley period. In the initial stages, the beads of semi-precious stones in different shapes and sizes were used as an aid to personal beauty. The beads of gold and silver were sparingly used by the rich people. The advances of metallurgy in Vedic era, made it possible to use largely gold and silver for fashioning of intricate jewellery. At the same time, the other materials, like ivory, wood, clay and terracotta were also used to fashion jewellery for the poor section of the society. Coming to Maurya-age, the major parts of the country were united under one paramount rule. The vast resources of the country and intimate relations of the Maurya emperors with west Asian monarchs might have introduced some new traits and traditions of west-Asian origin in Indian jewellery. Some of the ancient jewellery found from Taxila would suggest such a cultural blending.

The beginning of the Christian era is full of political turmoil and confusion in Indian history. The various nomadic tribes, such as the Bactrian Greeks, Sakas, Parthians and the great Kuṣāṇas had crossed the Indian borders and established their kingdoms in whole of the north-western regions of the country. This provided a further opportunity for the west and central Asian cultural norms and traditions to penetrate into Indian soil. Again, the opening of sea-routes led to the development of Indian foreign trade with the Roman empire as its chief customer.

The huge quantity of Roman gold was coming to India every year as a result of the brisk trade. The art of jewellery and work in precious stones were attaining unprecedented heights. However, the scant archaeological material is hardly adequate to form an idea of the alien forms or techniques, if any, introduced in Indian jewellery due to the cultural contact with west and central Asian world. Some of the jewellery pieces from central India, presently kept in the National Museum, New Delhi, are akin to the jewellery found from Himachal Pradesh and Punjab. Thus, the north-western regions seem to have preserved the ancient modes and traditions for the last two thousand years. However, the Buddhist motifs, floral

designs and animal and bird forms in these ornaments might suggest the Indian influence which might have travelled along with the migration of Buddhism to central Asian regions. The forms like, belt buckles, amulets and medallions are definitely of central Asian origin and the lavish use of semi-precious stones, like ruby, turquoise, coral and lapis lazuli bespeak of the characteristic quality of that region.

The jewellery found at Sirkap and Bhir, the two notable centres of the Taxila region, comprises of necklaces, pendants, earrings, bracelets, clasps, rings and hairpins, etc. The necklaces, made of many pieces strung together by thread or wire, can be attributed to Indo-Parthian and Kuṣāna period. The gold beads are usually hollow with small holes to be filled in with lac. In one of the elaborately made necklaces, "the larger pieces are centered with oval medallions of crystal cut-en-cabochen in a beaded border enclosed by two fish,facing one another with minute circlets of inlaid white cells between their heads and tails" (Jamila B.B., p.48).This probably indicates the beginning of "Kundan' work which later found much favour with the Mughals in India. The metals i.e. gold, silver and copper have been used to fashion the ancient forms of jewellery from Taxila. The falling down festoons from the necklaces and ear-pendants are made of thin entwined wire and are also sometimes studded with semi- precious stones, like the garnet, amethyst and corals. The various manufacturing techniques, like the filigree, repousse, moulding, heating, soldering and encrusting of stones are found employed in making the ornaments. The delicacy and boldness of design, accurate and precise modelling and the perfect finish of ornaments from the Taxila excavations would suggest that the art of jewellery had been fully evolved there.

The art-motifs employed in the jewellery pieces from Taxila are varied indeed. They exhibit a fine blending of the Hellenistic and Indian traditions.

The figures of Eros and Psyche riding the sea-lions in one of the gold pendants found from ancient Taxila might suggest "the traces of important and strong Greek influence which are not found in Southern and Eastern parts of India" (Jamila,B.B. p.53). Ofcourse,the Greek motifs are blended with the Indian lotus, crescent, lotus buds and other flowers. The Greek motifs in Indian jewellery must have been introduced by the Indo-Greek and Parthian rulers of Taxila.

The religious motifs, like the *Cakra* or Wheel, *Triratna* and *Svastika* are also noticed. The other motifs represented are the rosettes, the creepers and the circles. Sometimes, the pendants are shaped in forms of a 'crescent', 'tiger's claw' and the 'peepal leaves'.

In South India, the jewellery of the Ikṣvāku period from Nagarjunakonda is somewhat plain and simple as compared to that of the Taxila region. A necklace and ear-rings made of gold, along with the Buddhist caskets, were recovered from the Nagarjunakonda excavations in the Krishna Valley. The technique employed to fashion the Nagarjunakonda jewellery, datable to 2nd century A.D., is confined to Filigree. The beaten gold wires are fastened together and soldered to produce ornaments. The notable discovery of goldsmith's entire stock-in-trade, which included moulds of various designs and crucibles etc., from the Site 58 at Nagarjunakonda, is a positive evidence to show that the craft of jewellery had fully come into vogue in the Deccan of Ikṣvāku period (Sarkar & Misra 1972). Similarly,

the gold necklace from the Stupa-site at Gummadidurru, with fifteen beads including spacers, would further strengthen the above statement (Sarkar & Misra 1972).

Jewellery of the Gupta period

With the emergence of the mighty Gupta emperors on the scene, the political condition of the country attained solidarity and stability for a considerable period. Science and technology made rapid strides,resulting in an overall enrichment of people's lives. The stable political conditions and the material progress raised the living standards of the people in general and the nobility in particular. It aroused aesthetic impulse of the people who craved for the finer aspects of life and thereby set norms for beauty. The various treatises on the numerous arts and crafts were composed giving technical expertise and their characteristic features. It was an era of artistic effulgence and perfection.

Accordingly, the art of gems and jewellery reached the culminating points during the Gupta-age. The earlier ornaments were continued and modified and so also many fresh forms were introduced to suit the new social traits and traditions. The use of precious stones with splendorous shades on the glittering surface of the gold became the characteristic feature of the Gupta jewellery. It necessitated the "*Ratnaparikṣā*" or the examination of jewels, which was included among the sixty-four subsidiary branches of knowledge in Vatsyayana's *Kāmasūtra*. The Buddhist chronicle, *Divyāvadāna*, prescribes this science as a part of training to the sons of trading merchants (*Divya*, p. 26, 99-100). Another important work, *Bṛhat-Saṃhitā of Varāhamihira*, gives a vivid account of different gems, their provence, colours and other characteristic features (Kern, 1865). The numerous literary sources provide countless references to the use of gems for various purposes, such as their appliance in jewellery, costumes, furniture, seals and other objects of household. The gems were encrusted as well as inlaid on the objects of exceeding beauty. The art of cutting and polishing the precious stones was pursued with great vigour and industry.

Jewellery seems to have been in great demand during the Gupta period. The ornaments were worn all over the body. The *Amarakośa* gives a long list of the names of ornaments for the head, forehead, the ears, the neck, the arms, fingers, waist and feet.

Head Ornaments: During the Gupta age, the Kirita was a well known head ornament for the kings (Kālidāsa, *Raghu*, VI). The gems, *cūḍāmaṇi* and *makarika* (crocodile shaped jewel) were commonly worn by the ladies on the parting of the hair, the former at the back end and the latter on top of the head (Sivaramamurti, 1956). The ornament, *cūḍāmaṇi* was shaped like a full-blown lotus with petals, all composed of pearls and precious stones. The ornaments, like the *ratnajāla* (jewel festoons) and *muktajāla* (pearl festoons) woven in the hair of the ladies, are mentioned by Kālidāsa (*Raghu*, IX). This type of ornaments are noticed in the wall paintings of Ajanta and Bagh.

Ear ornaments: The ear-rings or *kuṇḍalas* were of many shapes. The *makara kuṇḍala*, showing the fantastic animal with curled snout, was very popular during the Gupta age. The *manikuṇḍalas* or the ear-rings fitted with jewels were greatly

admired (Kālidāsa, *Ṛtu*, II, 19). The festooning of hair with hanging pearl strings is not noticed before the Gupta-age. Hence, it must be a novelty of this period. The ear-rings shaped as leaf (*patra-kuṇḍalas*) seem to have been greatly in fashion. The leaf- shaped *kuṇḍalas* of gold (*kanakapatra*) are also described in literature (Sivaramamurti, 1956).

Necklaces : The most common necklace of the Gupta period, as seen in the sculptures, was the 'ekāvali' which consisted of a single string of pearls, variegated by a large sapphire in the centre. Kālidas has noted the beauty of this ornament when he says, "Remarkable is the beauty of the pearl itself, nothing to say when combined with the radiant sapphire" (*Raghu*, XVI). Varāhamihira mentions a large variety of necklaces, wherein they were named after the varying number of strings. For instance, the *Induchandā* (1008), *Vijayachandā* (504), *Devachandā* (81), *Rasmikalapa* (54), *Gucha* (32) and the like comprised of multiple strings (*Bṛh*; S. LXXX). *Nakṣtramālā* was a necklace having seven pearls in one string.

Girdles: The girdles were mostly made of gold. The name *hema* for the girdle might suggest its material as well. *Hemasūtra* was probably a chain of gold with precious stones in the centre. The other types of girdles, i.e, the *mekhalā*, *kāñci*, *kinkinī* and *rasanā* have already been referred to above. In fact, the 'rasanā' with a melodious sound of chains and the *kinkina* with a jingling sound of small bells had attained greater popularity in Gupta period (Kālidāsa,*Megh*. XIII).

Bracelets & Armlets: The various names such as the *valaya*, *aṅgada* and *keyūra* were common for the bracelets and armlets during Gupta-age. The bracelets and armlets were made of gold and encrusted with precious stones. The *Keyūras* were shaped as animal's heads. If it was without tassels, it was known as *Aṅgada*.

Anklets : The term *nupūra* and *maninupūra* are found mentioned in the literature of the Gupta period (Kālidāsa,*Raghu*, XVI). The *maninūpūra* must be studded with gems. Bānabhaṭṭa mentions the word, "Tulakoṭi" which means the anklets with two ends, each bearing a slight cubical enlargement as noticed at the ends of a balance beam (Sivaramamurti, 1956).

Finger Ring : The finger-ring or *aṅguliyaka* seems to have become popular during the Gupta-age. The finger-rings with a jewelled top *manibandhana* has been mentioned by the poet, Kālidāsa (*Śakuntalam*, VI).

The Gupta-age witnessed perfection in every field of Indian art. The high ideals and standard set by the artisans of the Gupta era invariably inspired the artists of the subsequent centuries to follow the same age-old forms, motifs and designs in their art and crafts. The cycle of progress had reached the highest point and it was now moving in the reverse direction. The most articulate sparingly used jewellery of the Gupta era, as seen through the wall-paintings and sculptures, is put to exotic use in sculptures of the subsequent periods. No doubt, some of the names and forms of the ancient jewellery are continued in literature and art of early medieval period of Indian history. For example,the terms, *cūḍāmani*, *makara-kuṇḍalas*, *nūpūra*, *mekhalā* and *ekāvali*, etc. were commonly used during the period of Harsa Vardhana. Some new names of ornaments also occur in literature.

During the 9th and 10th centuries, A.D., there does not seem to have occurred much change in ancient forms of Indian jewellery. The ornaments were in great

demand. Abu Zaid, who came to India during the period under consideration, remarked that the kings and nobles wore costly ornaments which were made of gold and studded with rubies, emeralds and pearls (Abu Zaid, p.14).

The kings preferred gems mostly of red and yellow colours (K azim, VIII). Pearls were profusely used as festoons in jewellery. The kings maintained a band of artists and skilled craftsmen in the court. Rajasekhara, a poet of the Gurjara-Pratiharas mentions the presence of the jewellers, gem-setters, and goldsmiths amongst artisans seated at western end of the royal court (K azim,X.). Amongst the favourite ornaments of the ladies, the *Cūḍāratna* or *Śikhāmani* was put on the hair; *Niṣka* was a necklace made of coins or the big golden beads; *Manilatā* was a golden chain studded with gems; *kuṇḍalas* were the ear-ornaments; *kaṭisūtra* was a golden chain for the waist and the 'Nūpura' or 'Manjirā' were the anklets (Kazim,V.). Some new names to be met in the literature of this period are the *Dalāvitaka* and *Sīsapatraka*. These are mentioned as ear-rings, which must have been shaped like lotus petals and leaves (Damodara gupta, 1924, p. 65). The *Valayakalapi* were the bracelets shaped as peacock (Damodara gupta, p. 345). The *Tittibhika* was a neck ornament worn by the ladies of the period (Damodara gupta, p. 739).

The early Muslim invaders from the Arab (Bagdad) did not leave any abiding impact on Indian culture. The Muslim rulers in India, prior to the Mughals, were constantly engaged in warfare to establish their political suzerainty. The historians too were obsessed with the political situations and left little record of arts and crafts. The extant specimens are not of much artistic significance. The Mughals, had a great regard for the Persian cultural norms and their interest heralded a new era and opened wider horizons for the Indian craftsmen. The Indian artisanship, which was passing through the stage of depression and stagnation, received a new lease of life. It acted with fresh vigour and enthusiasm to develop new techniques and perfection and thereafter produced masterpieces in fields of Indian art and crafts. Although, no significant new forms seem to have been introduced in Indian jewellery yet, the craftsmanship had considerably improved. The sophisticated taste and the magnificence shown by the Mughal emperors to Indian artisanship, gave an unprecedented impetus to the art of Indian jewellery. The talented artists of India used their indigenous skill and artistry to fashion the most beautiful ornaments. This happy blending of the alien taste and Indian workmanship provided a new look and extraordinary charm to the crafts of Indian jewellery.

Tools and Implements

The Indian goldsmith, popularly known as Sunār, works entirely with a small set of indigenous tools and implements at his command. All his work is basically manual where he depends entirely on his personal experience, dexterity and judgement. The profession was hereditary, carried from father to son without much external influence. The basic elements of the craft, the traditional forms, motifs and designs of ornaments and the indigenous materials for his work were based on oral instructions and experience. Every village had a family of goldsmiths who would fulfil the basic needs of the rural community. Ofcourse,the urban-based goldsmiths were comparatively more exposed to outside influences in so far as they could copy

the forms, motifs and designs of ornaments provided to them as models for fashioning new types of ornaments suiting the taste and traits of their new customers.

The urban-based craft of jewellery in India was a team work, wherein a band of skilled workers were involved to complete the work right from purifying the metal to the encrustation of finished gems. The work of refining of the various metals was done by a particular class of goldsmith, known as Nyariya. He did the work of melting old ornaments or purifying gold and silver from alloy. The work of a goldsmith was to prepare the skeleton ornament and send it to the 'Citera' for engraving. After completing the patterns on gold, the piece was sent to *gariā* who would chase patterns and designs. This work was called 'Gadhat'. The 'murassakār' or 'kundanasāz' was engaged for studding of the gems. Again, a different set of workers, called 'mināsāz' were engaged for enamelling. This type of specialisation in the city brought about much better finish than achieved in villages where a single individual *Sunār*, used to undertake the entire process single-handedly.

The tools and implements of goldsmith are few and simple. The apparatus for heating and melting the metals include a furnace (*angethā*), crucibles (*gharyā*) blowpipe (*nāl* or *phuṅkanī*) and small curved blowpipes (*bangual*). After melting the metal the *Sunār* uses a long narrow trough with a handle known as *reza* or *Pargahani* with which he converts the metal into a long bar. For hammering, there is an anvil (*nihaī*) and the hammer (*hathaurā*). He has various long and small tongs (*cimṭā* or *cimṭi*), pincers (*saṃsī* or *Zambūri*), scissors (*katrīs*), file (*retī*) and the chisels (*chhenī*) to do his job. For drawing wires, the *Sunār* uses the wire-drawer (*Jantra*), which is an iron plate perforated with circular holes of different sizes through which the metal bar is drawn out until it is gradually reduced to the thickness of an ordinary wire. A cube (*kensūlā*) of brass or bell metal (*kānsa*) with circular hollows at the side is used to hammer out the small plates of metal into separate halves of round ornaments, such as the *ghungru* (small chain bells), which are appended to the chains, bracelets and anklets. There are the dies (*thāppā*) of various shapes and sizes required for ornaments. The dies are used to bring out the patterns by hammering and heating. The dies are named after ornaments such as the *thāppā cūri* (a bracelet mould) and *thāppā tābiz* (amulet mould) and so on.

In addition to the above equipment and tools, the Indian goldsmiths used certain other instruments to do the filigree work. The heavy pincers (*siari*), light pincers (*atamgir* or *pilas*) are used for pulling wire. The *qualam* (pointed iron pen) is required for chasing the patterns. A set of *Sālais* are used for chiselling and engraving. The *Bālanca* is a hand brush made of hog's hair for cleaning. The Meghnala or the mica plates are required for arranging and soldering the wires of filigree work. The *Tāra Gola Nali* is a wooden cylinder to which the gold and silver wires are wound around. The *Hatol* is another instrument in the shape of a iron needle over which gold and silver wires are wound for making chains.

The few indigenous chemicals used by the *Sūnar* in the process of his work are the *Suhāgā* (borax) as a flux in melting metals and the mango parings (*amachul*) to clean and brighten the objects. The application of salt is completed with the help of sal ammoniac (*nausādar*) and alum (*phitkarī*). Finally, the *mānik ret* (ruby dust) is rubbed over the ornament to level the surface of the finished articles.

Various Techniques

The process of fashioning the jewellery in India involved various technique. The metal required for the fashioning of an ornament had to be first examined for the its purity through a special technique, called assaying. The familiar method for assaying was to rub the metal on the touch stone (*kasauṭi*). The rubbing of the metal on the *kasauṭi* left a mark of certain colour which used to suggest the purity of the metal or the amount of alloy of other metals contained in it. Similarly, the alloying was sometimes found necessary to give a certain hardness to the metal for working intricate patterns and design on its. The gold was alloyed with copper or silver and the silver was alloyed with copper or zinc. The soldering was done to join the different parts of the ornament together. The gold, silver and copper were mixed in soldering gold ornaments and silver and zinc in silver ones. The techniques is locally known as "Tåñkā".

The different types of works in fashioning the Indian jewellery can be divided into four major categories. Firstly, the *Sunār* hammers down the metal into desired shape or form of an ornament. He may also cast it in a die. Secondly, the patterns are brought out by chasing or embossing. Thirdly, the enamelling on the back of the ornaments and fourthly, the studding of gems.

Casting

At first, a resin model of ornament is prepared with the help of fingers alone. It is afterwards enclosed in a mixture of clay and cowdung. The enclosed model is provided with containing the metal and later placed on the fire. After gradual heating, the molten metal enters through the vent and reaches the resin model. The resin model melts ultimately and gives place to a similar model of molten metal. Thus, an exact replica or the resin model is produced in gold or silver. This is probably the crude form of the present 'cire-perdue' or lost wax method.

Dies or Thappā Technique

However, the ordinary method is to melt the metal and to hammer it into a desired form. This method is suitable to produce solid (*thos*) ornaments. However, if the object is hollow (*polā*), the two halves are produced and then joined together with solder. The patterned ornaments, like the ear-rings with floral designs, bracelets and amulets and produced by putting small circular pieces of molten metal on the dies (*thāppā*) and hammering them until the metal takes the shape required for an ornament. All the smaller units prepared in this process are put on plain pieces of metal at the back and joined together with solder. The ornament is again put in the fire for a few minutes and taken out for cleaning and brightening the surface. Later, it was passed on to *nakāṣ* for engraving artistic design on it, which were to be enamelled.

Gilding

The *Mulammas* or the beaten gold-leaf were applied by the skilled craftsmen called, Mulammasaz. It is the technique of gold- gilding. After heating, the gold

leaf is set with the help of an agate piece called, *Mahari* or *Mahara*. The ornament is then sent to Zilasaz who gives the finishing touches to the surface.

Filigree

The filigree is one of the earliest techniques employed in India for fashioning the ornaments. The work is done in pure silver. The metal is cast into long bars. The long silver bars are cut into small pieces and the same are beaten and drawn into wires, with the help of a *Jantra*. The wires are taken one by one and carefully arranged and cemented on a sheet of mica to produce parts of intricate designs and patterns. Later, the different parts are united by soldering. lastly, the process of cleaning and brightening the surface is completed to give a snowy appearance.

Enamelling

The enamelling is another technique which has been practised in India since remote antiquity. The enamel beads from the various Buddhist sites, like Sankisa, in India trace the history of enamelling to early historic period. Such enamelled beads are divided into two groups, viz; the white enamel on a black or cornelian ground and the black enamel on grey or white agate background. The enamel patterns are chiefly pentagonal, hexagonal, circles with dots in the centre, or else five rows of tiny spots or bands of two or three in number running round the beads. The circle and dot pattern is so arranged on the round beads as to form the tried symbol.

The enamelling in medieval India was generally applied in grooves. The motif or patterns were drawn by the Citera or artist and the piece was handed over to the goldsmith, who completed his work leaving grooves to be enamelled. The enameller or *Mīnākār* first cleaned and burnished the plate and when applied his colours in order of their hardness or the power of resisting fire, beginning with the hardest or that which most resists the fire. All the known colours can be applied to gold. The black, green, blue, dark yellow, orange, pink and peculiar salmon can be applied to silver. The white, black and pink colour only can be applied to copper. In order of hardness, the colours are white, blue, black, yellow, pink, green and red. The pure ruby red, being the most fugitive, requires a great care and precision of an experienced craftsman. The Jaipur enamellers were the best in handling this colour. The pink enamel of Banaras was equally famous.

The colours are mineral oxides which were obtained in opaque vitreous masses from Lahore. They are ground in postle and mortar and mixed with water. The colours are then filled in the grooves very cautiously with a brush much in the same way as a picture is painted. The paint, if over-flowed, is carefully wiped with a pieces of cotton. The articles is then left in the fire for half an hour or so, when the enamel firmly sets in. It is then rubbed with *kurand* or corundum-bone or *sohan*. The article is next repolished by heating it gently. The last process is to rub it with the file and clean it with the acid of tamarind or lemon. The enamelling was generally done at the back of Mughal ornements.

Another famous centre for a different kind of enamelling was at Pratapgarh. Sir George Watt has described this technique, as he says, "The article is made of a piece

of green or red coloured glass, or thick layer of enamel, the crude material which is imported from Kashmir", he further writes, "A frame of silver wire, of the exact size and shape of the glass, is next made, and across this is attached a sheet of fairly thick gold leaf. This is then embedded on lac and the pattern punched out and chased on the gold. The glass is then semi-fused, and while still hot the rim of silver and film of gold are slipped over the edge and pressed on to the surface of the glass. The article is again heated, until a sort of fusion takes place and the gold and glass become securely united. before mounting the article, a piece of silver tin-foil is placed underneath the glass to give it brilliancy".

Inlay Work

The origin of inlay work in India goes back to remote antiquity. There has been a wrong notion among the scholars that the inlay technique in India came from Damascus and hence, the name damascening.In fact, the origin of inlay work in Damascus appears to be quite late, not earlier than 13th century, as compared to its old Indian origin. The technology of a limited use of silver and copper inlay on bronze or brass objects in the Near East may indeed have migrated from the Abbasid heartlands during 11th-12th A.D. which, in its own turn, was influenced from Kashmir, a geographically much closer and adjoining region. The flowering of bronze casting technique in Kashmir is to be associated with the Karmotas, who assumed power in Kashmir sometime in 7th century A.D. The great Karmota king, Lalitaditya ruled over Kashmir in the first half of 8th century A.D. and it is possibly in his reign that the fine datable Buddhist images are largely found. Both silver and copper inlay was used, the silver mostly for the eyes and copper for the inlay of the garments. Buddhism appears to have continued in the eastern Iran and Afghanistan for a few centuries after the Islamic conquest and many such images must have been cast there during Islamic times also.

The influence of Kashmir on inlay-work of the Near Eastern Islamic world during the early Islamic period therefore would be a more logical conclusion. Perhaps this tradition, rather than the Abbasid, was responsible for the introduction of small quantities of inlay into Samanid and Ghaznavid bronzes.

The inlay of turquoise and copper for the eyes of lion-shaped incense burners, presently housed in the Louvre and Hermitage and signed by 'Al ibn Muhammad al-Taji are, indeed, reminiscent of the early Buddhist tradition. The pre-eminent tradition of the Samanid and Ghaznavid lands for the production of cast-bronze objects in a wide variety of shades would suggest that the thriving Buddhist tradition producing huge quantities of cast images in these lands prior to the advent of Islam might be responsible for the subsequent neighbouring Islamic tradition of inlay workmanship. It is only in the second half of the 12th and the beginning of 13th century that Khurasan and Herat in particular, produced inlaid bronzes and brasses of hitherto unparalleled splendour and intricacy. Here the quality of the casting and the sheet working is superb which would suggest a long-standing tradition in the past. The inlaid objects made of brass and copper found from Iraq and Syria follow the Iranian tradition. Damascus followed the same tradition during the 13th century A.D. Hence, it will not be incorrect to suggest that the inlay

technique in the Near East and the Arab world had reached from Kashmir which had an earlier tradition of bronze casting.

Inlay is meant to fill the depression by use of silver or copper wire on the surface of another metal. In India, inlay has generally been practised on the finished objects of metal, stone and wood. The main purpose of inlaying was to beautify the surface of art objects, may it be ornaments, weaponry or wooden furnitures, and for delineating floral motifs, human and animal figures and abstract motifs and designs in contrasting colours.

Studding of Gems (Mānikya-bandhan)

India has a hoary tradition of fashioning precious and semi- precious stones. The discovery of crystal reliquaries from a number of Buddhist sites belonging to 3rd-2nd century B.C., are adequate proof to the technique of stone carving in India. The process of fashioning some precious and semi-precious stones to produce exquisite art forms is one of slow and patient abrading with the help of abrasives which are powdered out of harder stones. Thus, the term carving is erroneous, as the precious stones were never cut with steel. The abrasives used right from the ancient times are quartz, sand, crushed almandine, garnets, corundum, diamonds and, in modern times, Carborundum. Thus abrasives are prepared by pounding, grinding and sifting of raw materials and later on turned into paste ready to be applied. Tools are generally made of wood and metal. Amongst the tools commonly used by the craftsmen are the lap wheels and diamond drills of various sizes. The difference between the Chinese craftsmen and Indian artisans is that in China they used treadle lathe in place of the bow lathe which is still used in India by those craftsmen who have not succumbed to the electric motor. After fashioning the object in its desired shape, polishing was done to provide it with a glossy surface. The work of polishing was done mostly with the help of a stone, known as "Mohari".

After the completion of the enamelling, the hollow ornament is filled with shellac on which precious stones are set. The ornament was sent to a different craftsmen, *Mānikya-bandhaka* or the *Kundansāz*, who used to set the precious stones over it. "The grooves are initially made for this setting in the form of an artistic scroll. A piece of thin silver sheet (*dāk*) alloyed with three ratis of pure gold to a tola, to prevent it from tarnishing, is cut to shape, made concave and then highly polished. This is then fixed in each groove to give lustre to the stone. Upon it is placed the stone and then it is set. In the case of coloured stones, if its colour is light, the *dāk* is tinted with transparent colour, or the back of the stone itself is given a tint called *Joban*. The purest gold leaf is employed for this setting, which is well pressed around the gems with a steel bit, forming an edge around them. The thinner this edge is, the better it looks. In ancient India, the precious stones were generally set in their original shape. However, if a spot was detected, the entire piece was covered with facets in order to hide the flaw. As it has been pointed out by a scholar, "upto 14th century, pierced stones cut on cabochon were the greatest fashion". The gems were later set by the Kundansāz by using lac, tinsel or gold foil, prepared by the Bindligar. In fact, the *Kundan* is the ancient name given to the fine variety of

purified gold, the foils of which were set at the base to hold the gem in its place firmly. Later, the work itself was known as *Kundan-* work. In ancient jewellery, sometimes the crystal is found encrusted in place of precious gems. With the advent of the British rule in India, the gems are set more with 'open claw' technique, which leaves the underside of a stone clear. The polishing was done keeping in view the original shapes and colour of the stone. The chased surface of the ornament was rubbed with agate to produce a smooth and glittering surface.

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Furniture

K. KRISHNA MURTHY

Man's predilection for comfort has created a host of house- hold articles. Furniture is one among them. In the manufacture of furniture, wood has always been the basic material due to several reasons. It is available wherever conditions have favoured human living. It is easily workable to different decorative designs. It can be joined by many contrivances viz., by nailing, glewing etc. It produces less noise under impact than other materials of equal strength. It is relatively light in weight. It may be easily repaired when broken. It possesses intrinsic beauty in an infinite variety of colour, texture and pattern. It can be worked in many ways to enhance beauty. Moreover, in a country like India where wood is amply available, it is probably the only material used most commonly. Again, it appears that in early times metals did not find favour with the Indians as it did with the ancient Greeks and Romans in the fashioning of furniture. This may just as well be due to the availability of excellent quality of wood within the country itself.

However, at the same time wood has the greatest disadvantage too. It is a perishable material. The hot and damp climate of the country has made its survival for long centuries impossible. The total absence of any piece of furniture from the excavated remains is undoubtedly due to its being fashioned out of wood or similar other perishable material.

Literary Evidence

The ancient Indian literature abounds with references to the furniture known through the ages. The common Indian term to denote furniture in Pali, *Senāsana* and Sanskrit, *Śayanāsana*. The *Śayanāsana* or *Senāsana* is a compound consisting of two words — *Śayana* and *āsana*. When furniture is meant to be denoted in a collective sense we have the use of the form *Senāsanam* or *Śayanāsanam* and where it is meant to be denoted in detail, we have the use of the plural form *Śayanānyāsanāni*[1] (Shastri, 1969, p. 250). Thus, furniture was technically known as *Śayanāsana* or *Sayyāsana* corresponding to Pali *Senāsana*.

As early as in Vedic period we get references to the furniture articles. The terms like *Paryaṅka* (*AV.* XV. 3.3), *Āsandi* (Macdonell & Keith, 1912, vol. 1. p.71), *Proṣṭha* (*ṚV.* VII. 55.8), *Talpa* (*ṚV.* VII. 55.88; *AV.* V. 17.12; XIV. 2.31.41; Taitt, S. VI. 2.6.4), *Vāhya* (*ṚV.* VII. 55.8: *AV.* IV. 5.3, 20.3; XIV. 2.30), *Śayana* (*AV.* III. 2.5.7; V. 29.8), *Upabarhaṇa* (Macdonell & Keith, 1912, Vol. 1, p.71), *Upavāsana* (Macdonell & Keith, 1912, Vol. 1, p.71), *Upastaraṇa* (*ṚV. IX.* 69.5; *AV.*V. 19.12; *Kaus. Up.* i.5) *Upadhāna* (*AV.* XIV. 2.65) denote the furniture known to the Vedic India. *Paryaṅka* denoted a seat for the Brahmins (*Kauṣ. Up.* i.5). It corresponded more a throne (Weber) and the *Pāllaṅka* of the Buddhist text and the *Paryanka* seem to connote the same meaning, throne and interestingly it gets frequent sculptural and mural depictions.

The *Āsandi* type of furniture was a long reclining chair resembling the modern sofa. The *Atharva Veda* (XV. 3.2. cf. seq.) informs that it had two feet, length-wise and cross-pieces forward and cross-cords, showing that it was made of wood (*udumbara)* and also cording. According to the *Śathapatha Brāhmaṇa* (V. 4.4.1) it was an elaborate seat made of Khadhira wood, perforated (*vi-tṛṇṇa)* and joined with straps (*vardhra-yutā*). This *Āsandi* type of furniture finds place in the lithographic delineations at several places.

The *Proṣṭha* was a bench (*Śat. Br. VII.* 55.8) and the seats with solid lower structure and without arm-rests depicted in the sculptures in all probability, represent the *Proṣṭha.*

The term *Talpa* (*ṚV.* VII. 55.8; *AV. V.* 17.12; XIV 2.31.41.; *Taitt. S.* VI. 2.6.4; *Taitt. Br.* II.2.5.3; *Pañc. Br.* XXIII. 4.2; XXV. 1.10), *Vāhya* (*ṚV.* VII. 55.8; *AV.* IV 5.3, 20.3; XIV. 2.30) and *Śayana* (*AV.* III.25.1; 29.8; *Śat.Br.*, VI.5, 1, 2, 7, 4) denoted bed or couch. One made of *udumbara* wood is mentioned in the *Taittirīya Brāhmaṇa* (I. 2.6.5). The *upabarhaṇa* and the *upadhāna* were the pillows or cushions provided invariably to *Āsandi.* The *upavāsana* and *upastaraṇa* were the coverlets generally used for the seats.

Several articles of furniture find mention in the Sūtras. The house holder is enjoined upon to ascend a couch at the conclusion of Śrāvanā sacrifice. A seat called *Āsandi* had four legs and was inter-woven with cords of Muñja grass. The *Baudhāyana Śrautasūtra* (X, 12) and the *Śaṅkhāyana Śrautasūtra* (XVII, 2, 6-9) lay down that the *Āsandi* (made of *udumbara* wood) legs should be one span high, that the length-wise and cross-pieces of this seat should be one cubit long and that it should be woven with cords of Munja grass. The *Vaśiṣṭha Dharma Sūtra* (XII. 36) forbids a *snātaka* to take his meals on a chair. A soft seat called *Bhadrapītha* is mentioned in the *Paraskāra Gṛhya Sūtra* (I. 15.4). The priests of the Mahāvrata rite were allotted *Bṛsīs*, cushions of grass (*Kāt. Śr..* XIII. 3.1 ; *Sāṅk. Śr.* XVII. 4.7). The skins of a red bull and a black antelope were used as seats on sacrificial occasions. Besides, a plaited seats of various kinds of grass was also in vogue (Ram Gopal, p. 156.)

As examples of household furniture, Pāṇini (Agrawala, 1953, p. 144) in his *Aṣṭādhyāyī* mentions *Śayyā* (bed), *Khatvā* (cot), *Paryaṅka* or *Pālyaṅka* (couch), *Āsandi-setti* (a royal throne), *Viṣtara* (an ordinary seat) and *Parpa* (a wheeled chair for disabled persons). Interestingly, all these are represented in the sculptures.

Much can be known about the furniture from the Jaina and Buddhist literatures. In Jaina literature we come across furniture articles like rich beds, cushions, pillows, chairs etc. Among the marriage gifts mention has been made of *Pāviḍha* (foot-stool), *Bhisiyā* (seat), *Pallaṅkāya* (couches) and *Paḍisijjā* (sofa). Various kinds of chairs like swan chairs, heron chairs, eagle chairs, tall chairs (*oṇaya*), sloping chairs (*panaya*), long chairs, fine chairs (*bhadda*), winged chairs (*pakkha*), crocodile chairs, lotus chairs, and *Disāsovatthīya* chairs are mentioned (Jain, J.C, 1947, p.157).

The Buddhist texts go long way in supplementing the history of the furniture of the period. The furniture items such as *Āsandi, Miḍhi* (bench), *Pālliaṅka* (throne), three-legged chairs, *Mañca* (seat or bed stead or couch), *Vidalamañca*, or *Vettamañca* (cane-seat), *Kocca* (cane-bottomed chairs), *Pattakaṇḍolika* (wicker stands), *Bhojānaphalakas* (tables), *Pāda-piṭhas* (foot-stools), *Bhisi* (bolster), *Bimbohaṇa* (pillow) etc., are mentioned in the Vinaya texts and interestingly, many of these articles are represented in the sculptures and murals of the period under study.

Bharata in his *Nāṭyaśāstra* (Ghosh, 1950, I, pp. 234-36) prescribes seats according to the status of the people and this incidentally throws light on the variety of furniture known to the period. Thus, gods and kings in a royal court are to be given a lion-seat (throne). The priests and ministers are given cane- seat. The commander of the army and the crowned princes should occupy *muṇḍa seat*. The Brāhmins will occupy the wooden seats while the other princes would take carpet seat (Ghosh, 1950, 1, p.235).

Similarly the chief queen should be given a lion seat in a royal court. The female relatives, wives of the kings other than the chief queen should occupy *muṇḍa* seat. The wives of the priests and ministers have been given cane-seat. The concubines of the kings are given seat consisting of cloth, skin or carpet. The wives of brahmins and female ascetics are provided seat made of wood (*Paṭṭa*). The wives of the Vaiśyas are given cushion seats and for the remaining women the ground will be the seat. But, one can take any seat according to ones own liking while residing in ones own house.

The seats for the ascetics should be according to the rules of the order they are observing. The performer of the sacrifices should sit on *vṛṣi muṇḍā* seat or cane-seat. The king should offer seats equal in height to that of his own to persons equal to him. To the persons of medium importance, the seats of middle height and to persons who are superior to him, should be given a more elevated seat, while the lowly persons are to be seated on the ground. What is interesting is that in the lithic representation, many of the rules prescribed by Bharata in his *Nāṭyaśāstra* are well answered. Thus, the kings, queens, princes, sages, brahmins at times in sculptures and murals are given prescribed seats as enjoined in the *Nāṭyasastra* of Bharata.

Kālidāsa's references to the furniture articles are copious. Several kinds of furniture items like thrones, high seats, benches, bedstead, boxes etc., are mentioned in his kavyas (Upadhyaya, 1947, pp. 214-216). *Siṃhāsana* (*Raghu*, VI. 6), the throne of the king was made of gold with set gems. There were also other seats made of gold and of precious stones which ought to have been the property of the rich (*Raghu* VI.4; VII. 28). There is also reference to beautiful seats made of

ivory covered (*Raghu*, XVII. 21) with white covers. Again *Bhadrapīṭha* or *Bhadrāsana* was another kind of seat in circular or rectangular shape (*Raghu*, IV.; See also Gopinatha Rao, 1. p.20).

Vistara was also an honoured seat, a high seat worthy of royal household. In all probability, those rich seats depicted in the Ajanta murals may represent *Vistara* type of seats. Besides these, there were benches and bedsteads. *Mañca* was a bench. Ācharya explains it as a bedstead, couch, bed, a sofa, a chair, a throne, a platform, a pulpit (Acharya P.K. 1927, p. 461). *Talpa* was again a high bedstead (Raghu. V. 75; XVI.6). The coverlets like *Uttaracada* and *āstaraṇa* are also mentioned in the kāvyas (Raghu. V. 65; XVII. 21; VI.4). The *uttaracada* appears to have been a bed cover or a cover to *Āsandi* (sofa). The other coverlet *astaraṇa* seems to have been used for covering chairs, cushions and the like.

Boxes were also a necessary furniture of the household and have been variously referred to as *Manjusa*[2], *Karaṇḍaka* and *Talarantapidhāna*.

Some of these furniture articles described by Kālidāsa do find place in the early Indian sculptures and in the Ajanta Paintings.

Later Śilpa texts like *Mānasāra* (Acharya, P.K. VII. pp. 298, 304, 380, 459, 499, 522 etc), recounts furniture articles and their prolific use in chapter XLIV. The words like *Siṃhāsana*, *Mañca*, *Mañcali*, *Pallaṅkāsana* etc., are referred to mean the furniture material. The *Mānasara* mentions a throne marked with lion[3] (Ed., Acharya, P.K. XLV. 204, 206). In fact, the *Manasara* enumerates ten kinds of thrones namely — *Padmāsana*, *Padmakeśara*, *Padma-bhadra*, *Śrī-bhadra*, *Śrī-viśāla*, *Bhadrāsana Padma-Bhandaka*, *Śrī-mukha*, *Vijaya* etc. Besides, there is another throne known as *Vajrāsana*.

Again, the *Mānasāra* refers to several words such as *Kakaṣṭa*, *Khaṭṭaka*, *Khatva niṣadya*, *Paryaṅka*, *Mañca* and *Mañcali* which are synonymous and all mean a bedstead.

According to the same work *Paryaṅkas* are of two kinds viz. *Balaparyaṅka* and *Paryaṅka*. The former is intended for the children while the latter is meant for elders. They are distinguished by their sizes. Interestingly, of the Āgamas *Suprabhedagāma* deals with the furniture articles like *Āsana* (chair, seats), *Paryaṅka* (bedsteads, couches etc), *Siṃhāsana* (thrones) (Acharya, P.K. 1927, p. 619).

In *Amarakośa* (2.3.138) we get scanty references to the furniture articles. It also refers to the word *mañca*[4] to mean a bedstead.

We have clear evidence in the Vātsyāyana's *Kāmasūtra* of the typical articles of domestic furniture then in use among the fashionable people, Nāgarakas. The articles that Vātsyāyana first draws attention to in the Nāgaraka's apartment are two couches with beds, soft and comfortable and spotlessly white, sinking in the middle and having rests for the head and feet at the top and the bottom. At the head of his bed is a *Kūrca-sthāna*, a stand or perhaps a niche for placing an image of the deity he worships, besides, at the head there is also an elevated shelf serving the purpose of a table, whereon are placed articles necessary for his toilet in the early dawn. On the floor is a vessel for catching the spittle. On the wall, on *Nagadantakas*

(brackets) are arranged his *vinā*, a casket containing brushes and other requisites for painting, a book and the garland of the Kurantaka flower.

Not far from the couch, on the floor, is spread a carpet with cushions for the head and besides, there are boards, for playing a chess and dice. Outside the room is the Nāgaraka's aviary where are hung cages of birds for game and sport (Chakladar, 1954. pp. 109-110).

Varāhamihira's *Bṛhat Saṃhitā* offers adequate information about the furniture which prevailed in his time. The words like *Śayana* or *Śayyā* (bed and bedstead as a whole), *Khatvā* (cot), *Paryaṅka* (couch or high seat), *Āsana* (a seat) *Bhadrāsana* or *Bhadrapīṭha* (throne), *Pīṭha* (a stool or a seat), *Upadhāna* (a pillow), *Śayanācchādana* or *Śayanāstāraṇa* (bed sheet) are mentioned in the *Bṛhat Saṃhitā* to constitute furniture articles known to Varahāmihira's time (Shastry, 1969, p. 251). The measurements of the couches meant for the kings, princes, ministers, army-chiefs and royal priests are prescribed. In the manufacture of a couch the *Pradakṣiṇāgra* order should be strictly adhered to. *Paryaṅkas* were usually made from the timber of a single tree. The *Paryaṅka* meant for royal household was fabricated from the sandal wood, covered with gold and decked with jewels.

Bhadrāsana was a royal seat and it was also called *Bhadrapīṭha*. In the ceremonious ablutions, the king sat on a *Bhadrāsana* placed over the skins of certain animals (Shastry, 1969, p 254). It appears from the *Rāmāyaṇa* (II.26.17) that it was a sign of royalty and carried by an attendant in front of the king (*Raghu*, XVII. 10).

In the early Indian civilization, wood had always been the basic material in the manufacture of furniture. Owing to its perishable nature and the hot and damp climate of the country made its survival for long centuries impossible. The total absence of any piece of furniture from the excavated remains is undoubtedly due to its being fashioned out of wood or other perishable material. We have therefore to depend solely on the plastic representations of furniture, if we seek to comprehend the ancient Indian furniture. For this, the sculptures of Barhut, Sanci, Amaravati, Nagarjunakonda, Gandhara, Mathura and the murals of Ajanta and sculptures of later period under review form a potential source of the study. The contemporary literary sources form a vital source in supplementing the sculptural and mural data of the furniture. They refer to the variety of furniture articles and amazingly, many of them find place in the lithic and mural representations.

Broadly, the furniture as gleaned from the ancient Indian sculptures and murals comprise thrones, chairs, wheeled furniture, seats and moras, wicker stands, foot-stools and bed steads of which majority of them are indigenous while a few of them betray foreign influence.

The thrones with solid base and devoid of arms and back can be identified as *proṣṭha* of the *Ṛgveda* or the *midhi* of the *Cullavagga*.[5] It is said in *Vinaya* (iii, 163) that *midhi* is generally built against the outer wall of the house of hut. It is made of hardened mud with two wooden legs in front. It is a bench used to sit or sleep on. Invariably, this throne is occupied by the Buddha as is evident from their depictions in Amaravathi, Gandhara and Nagarjunakonda sculptures. Similarly, the small thrones with or without arms but having pillar shaped legs probably represent the

Pallankas (Pali) or *Paryaṅka* or *Paryaṅkika* (Sanskrit) (VP. Culla VI. 2-A). The *Pallaṅkas* which have no arms are known as *Addhapallaṅkas*. The legs of the throne seem to have been fixed by the turnery technique. The chief novel introduction by the Greeks was the widespread use of turnery after 6th century B.C. The art of turning on the lathe was probably developed in the wood-producing areas of the Middle East whence it spread slowly to the Greek mainland. In the latter Hellenistic period, turning was introduced into Egypt and other parts of the Roman world. In all probability this technique of turnery was the introduction of the Greeks and Romans into India with whom India had contacts from the early times. These thrones persist in the early Indian sculptures since Śātavahana period. But they became very common in Vakāṭaka-Gupta period and are known as rich seats. Some of these seats as seen at Ajanta are decked with peals and diamonds and they probably represent *Ratnāsanas*. Such furniture involved the intricate technique of inlay of semiprecious stones. At times, they were quite ornate with incised geometric and floral patterns. Further, the thrones having animal figures (lions) as arm-rests or legs or both can be identified as *Siṃhāsanas*. Their widespread distribution in early Persia perhaps proned Stuart Piggot to their origin to western Asia. This is evident in the light of the Persian impact on the imperial Mauryan era. However, *Siṃhāsanas* gained popularity in the subsequent centuries of the Christian era as is evident from the frequent depictions in the sculptures of Amaravati, Nagarjunakoṇda, Mathura etc. Their popularity seemed to have reached zenith, particularly in Śātavahana and Ikṣvāku periods in the 2nd-3rd centuries A.D. But they became rare in later period and apparently seemed to have been replaced by rich seats or *ratnāsanas* as is evident from the mural depictions at Ajanta. Another interesting throne with prancing deer-supports as seen in the Ajanta frescoes denotes *Mṛga-siṃhāsana* (Dhavalikar, p. 93).

The large thrones (*āsandis*) are in no way different from the smaller thrones except that they provide accommodation for two or three persons. These large thrones or *sofas* did not gain favour in early period. However their popularity seemed to have increased in the late Śātavahana and the Ikṣvāku periods but again dwindled in the Kuṣāṇa and Vakāṭaka periods. It is quite probable that these large thrones could have been the contribution or the innovation of the Śātavahanas and the Ikṣvākus. The modern name *Sofa* is of Eastern origin and was first used in 1680 to designate a Diwan like seat in France. The same type had also been called *Canape*. It has a back and arms at each end but was distinct from the settee by its greater comfort.

Besides the small thrones, there were also three-legged and high backed chairs with armrests (*Pāllaṅkas*) or without (*addha- Pāllaṅkas*). They are represented only at Amaravati and Nagarjunakonda. Further, the chairs depicted at Nagarjunakonda are shown as used exclusively by the women. It is interesting to note that somewhat similar chairs with sloping or arched out backs known as *Cathedras* (Krishna Murthy p. 41) were used exclusively by the women of the Roman period.

The most familiar types of chairs were known in Egypt, Greece and Rome in ivory, metal, stone and wood. The well-known folding or 'X' type chair commonly found in the Egyptian tombs was often carved with animal forms and covered with

skin. This Egyptian furniture has possibly become the basis of all the later styles. In India, China and Japan furniture of brass, bronze and iron of great antiquity are found. Stone furniture was also not uncommon. However, wood is probably the only material used most commonly and it appears that metals did not find favour with Indians as it did with ancient Greeks and Romans in the fashioning of furniture. This may just as well be due to the availability of excellent quality of wood within the country itself.

As for the wheeled chair, only the Nagarjunakonda sculpture reveals a wheeled chair. Pāṇini mentions a wheeled chair (*Parpa*) used by the disabled persons. (Krishna Murthy p. 43). Probably, the utility of the chair depicted in the sculpture may be different from that known to Pāṇini.

The cane seats or *morās* were generally used by all sections of the society irrespective of their status. The rectangular seats (*mañca*) did not find favour at Sañchi and Mathura. Evidently, the small thrones with solid low-structure were developed from these rectangular seats.

The rectangular low seats represented at Ajanta resemble very much the modern *caukis* used in North India in the present day. Sometimes hermits as shown at Ajanta used rectangular wooden blocks. Itsing informs that such blocks of wood were widely used by the ascetics more especially by the junior members of the Buddhist order at the time of taking meals. Interestingly, such blocks of wood were widely used by the ascetics more especially by the junior members of the Buddhist order at the time of taking meals. Interestingly, such blocks of wood are still in use in South India being utilised for similar purpose and are known as *Pītalu* in Telugu language.

The cane-seats were used freely and did not remain the monopoly of any particular section of the people. The cane-seats were the most favoured item of furniture during the Śātāvahana and the Ikṣvāku periods. Sometimes the cane-seats (*munda*-seat) were used by princes as prescribed by Bharata in his Nāṭya Śāstra. It is quite probable that the *morā* might be related to the word *munda* as both signify identical form and material. These cane-seats which were in profuse use in early period became rare in later period and gave place to rich seats. When these cane seats had backs, they were called *Vidālamañcaka* or *Vetramañcam*. The wicker-stands or *paṭṭa-kaṇḍolikas* of Cullavagga were however rare and at times when these were used as dining tables, they represented. *Bhojana Phalakas* of Buddhagosha.

The foot-stools (*pāda-pīṭhas*) constituted an important article of furniture in the Indian house-hold. The foot-stools were generally provided to high thrones. Evidently, the height of the throne necessitated the foot-stool. They were rectangular or square or circular or oval or octagonal in shapes. Some of these foot stools interestingly resemble the *Jala-caukis* of Bengal or *Caukis* of Uttar Pradesh.

The bed steads (*mañcas* of the Buddhist literature or *Vettrapaṭṭikas* of Bāṇa) were many. The beadsted with pillow (*bimbohana*) and coverlet (*uttaratharaṇa*) arranged on the bed usually constituted the *Senāsana* (bedding). Sometimes, bed steads had elephant faced legs as seen in the Gandhara sculptures. In fixing the legs

to the cot the technique of turnery seemed to have been employed. Mats and mattress (*tūlikas*) were used for sleeping on the floor. Interestingly, *cilimika* (carpet), *Tina- Santharo* (grass-mat), *Panna-Santharo* (leaf-mat) were all known to the Buddhist period. Pillows and cushions were used freely. The roll cushions used resemble the present day lod and the circular cushions resemble the modern *tākiās*.

The jewel boxes (*ābharaṇa samudgakas*) and the betel boxes (*tāmbūla-karaṇḍas*) were all known. At times, these betel boxes were also made of ivory (*dantasapharuka).*

Owing to the trade contacts between India and the west, during the succeeding and preceding centuries of Christian era, India came into contact with many foreign countries. As a result, the impact of foreigners on India and vice-versa was inevitable. Thus the *throne* with pillar shaped legs and side arms but devoid of back is one such example among furniture. This throne which was only available in early period betrays a clear Hellenistic influence. Such seats with side arms were very common in Hellenistic and Roman world from where this type appears to have been found its way into India. However, it does not appear to have found favour in the later period due to the reasons that it has not afforded to sit in the true Indian fashion of the cross- legged posture.

Again, the wheeled brazier represented at Ajanta seems to be non-Indian. Such wheeled braziers were very common in the classical world and were used for carrying food from kitchen to the dining table. It is interesting to note that the movable braziers of iron resembling the classical pattern are reported to have been discovered from the excavations at Taxila (Krishna Murthy, p.44).

The three-legged stool or tripod represented in the Gandhara sculpture distinctly betrays Hellinistic origin. Such stands existed in Egypt in modest from as altars. The present example might have been introduced to India by the Greeks. Later in Roman period, these miniature tripods developed into an elegant tripod in metal (Krishna Murthy, p. 99).

The tables represented in the Gandhara sculptures and the murals of Ajanta show foreign impact. The X-shaped table revealed unmistakable Greek origin. Evidently the Greeks in turn borrowed such tables from the Egyptians. Similarly, the table in the form of tripod sculptured at Gandhara may represent Greek ornamental table *dephica*. In all probability, the present table could have been developed from the Greek's costly table *monopoded* or *orbes* which rested on one leg with a wooden top cut out of a single leg in the whole of the diameter (Seyfert, 1891, p. 610 a).

The table with rectangular top mounted on two sets of legs, each pivoting medially on the other as revealed in the Ajanta murals is of foreign origin. A finest example of such table datable to 1st century A.D. is reported from Pompeii.

It is quite likely that this type of table found its way into India through Greeco-Roman world and continued to be in use though rarely, till 5th-6th centuries A.D. as is evident from its representation at Ajanta and Ellora.

The dressing table sculpted at Ajanta in the conceptions scene is non-Indian and bears striking resemblance with the ultra-modern examples of our times. Another variety of dining table low in height and having oval top mounted on curved legs,

represented in the Ajanta paintings has foreign origin. It is interesting to recall that Athenams refer to similar dining table of the Mauryan emperor Candragupta. As is evident from the statement of Megasthanese the antiquity of such tables can be traced to 4th century B.C (Dhavalikar, p. 100). It is probable that such tables came into India in the 5th century B.C. during the time of Persian invasion. Various kinds of curtains or blinds (*Cakkalikas*) were in use. A movable curtain (*Samsaraṇa or Ugghatanakiṭīkā*) gets represented at Nagarjunakonda. Curtains of different colours in three rows (*tiraskrani*) get depicted in a royal court (Dhavalikar, p. 102) in the Ajanta paintings. Curtains are usually referred to as *Yavanikas* or *Javanikas* and the Ionian Greeks are generally credited with their introduction in India. Perhaps in early period, curtains were imported from abroad for merchants on the western coast are said to be buying foreign curtains (*IA*. XVI. 1887, p. 8).

Thus, the furniture articles known to ancient civilizations were copious and various of which some of them remained prototypes or the forerunners of the furniture of the later periods.

Furniture (9th century A.D. to 1200 A.D.)

The furniture of the period under review distinctly betrayed as we see in the following pages, the continuation of the many of the furniture articles of the preceding period which served as their prototypes. The furniture articles like thrones, seats, *moras*, the cane seats, foot-stools, bed-steads etc., continued to constitute the furniture articles of the period. One can see no change either in models or in the technique of their manufacture during this period. The types of thrones as usual included those having either animal legs or solid ones with or without arm-rests. The throne having lion as support and lion head terminals at top bar of the back of throne apparently represented *Siṃhāsana*. The *Yuktikalpataru* while listing out different types of furniture speaks of *Siṃhāsana* of eight different varieties in accordance with the nature of the animal supports. It also mentions of the wood, precious metals and stones that are to be used in the make of *Siṃhāsana*. It further states that this throne should be made of sandal wood (*candana*). The Chinese traveller Yuan Chwang also speaks of *Siṃhāsanas*. "The sovereign dias", he observes "is exceedingly wide and high and is dotted with small pearls" what is called lion seat is covered with a fine cloth and mounted by a jewelled foot-stool. However, the lion motif appears to be one of the most ancient decorative symbols probably typifying the royal nature of the furniture of the early people. As regards the large thrones or *sofas* they continued to be in use throughout 9th-10th century A.D. also.

The seats circular or rectangular with foot either plain or curved or with solid base were seen in use. The bed-steads did not show any remarkable change either in the construction or in its technique. The technique of turnery was adopted in their making.

The period between 10th to 12th centuries A.D. even did not show any deviation in the models of the furniture articles or in the introduction of the new items of furniture articles. During this period as can be found in the Kākaṭīya and Hoyasālā periods, the furniture articles persisted to constitute the same

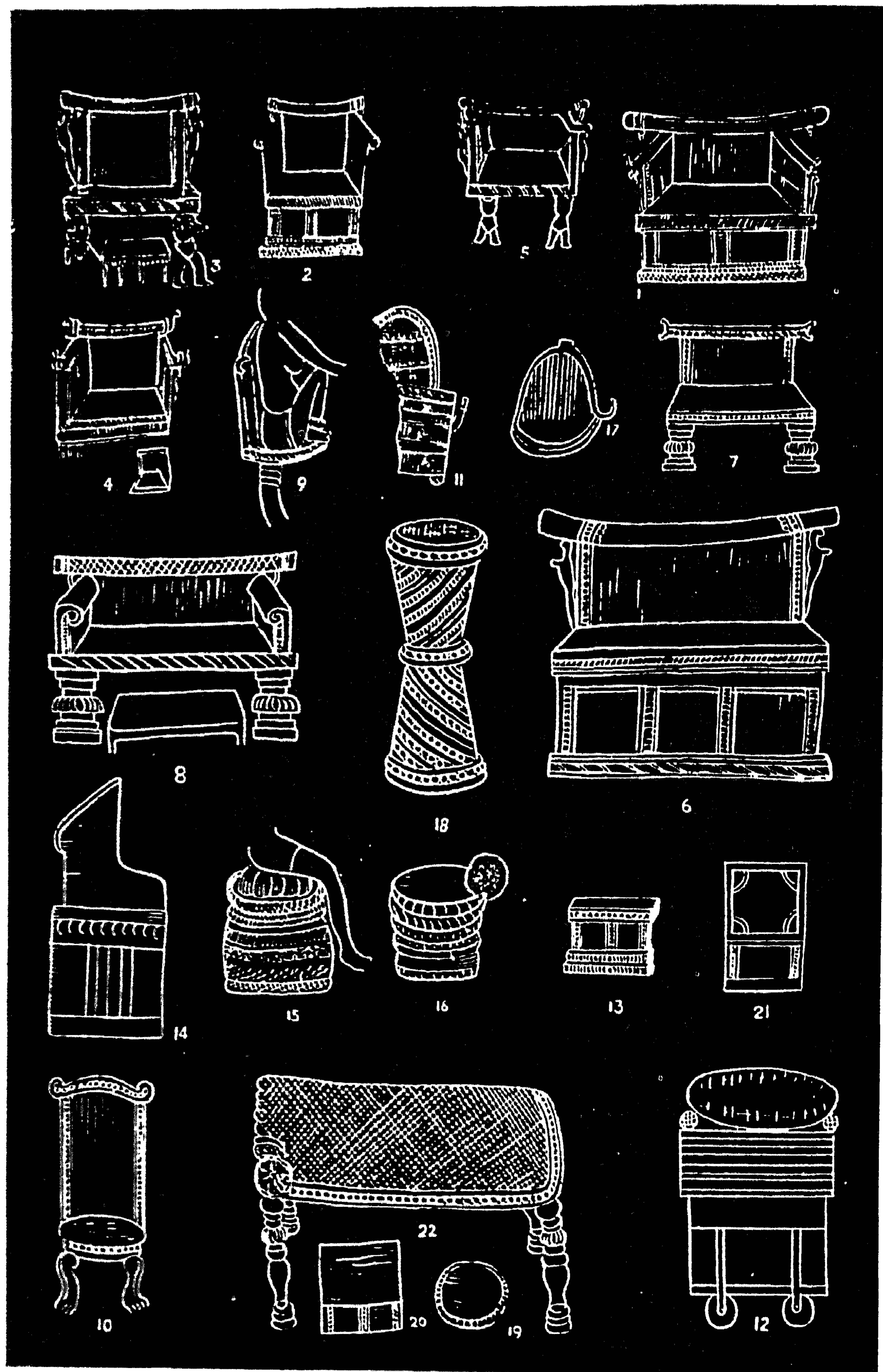


Fig.1 Furniture - Ikṣvāku period (3rd-4th century A.D.) 1 to 5 Thrones. 6 to 8 Large thrones. 9 to 11 Chairs. 12 Wheeled chair. 13 to 18 Stools and Cane-seats. 19 to 21 Foot stools. 22 Bedstead

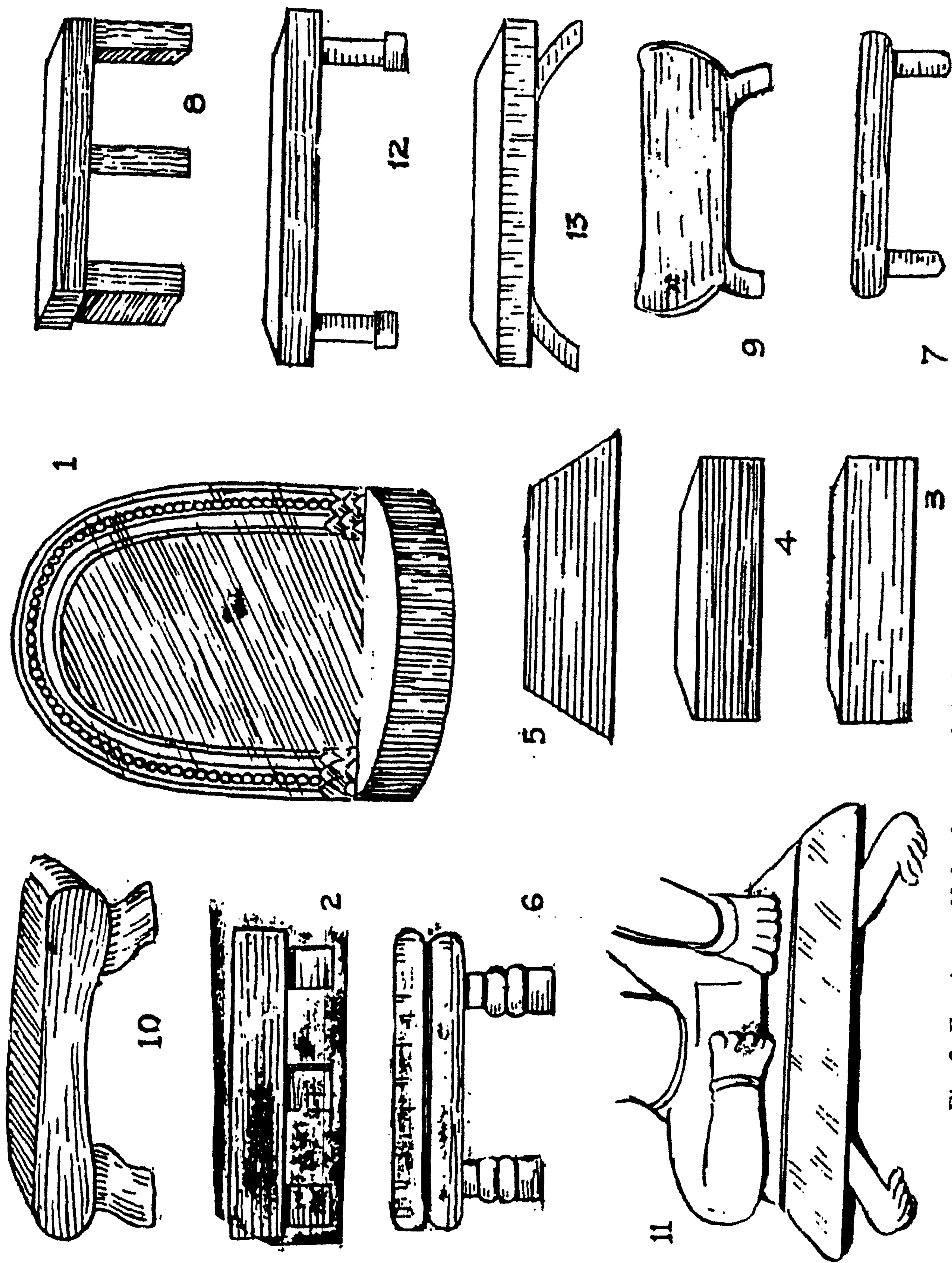


Fig. 2. Furniture - Nolamba period. 1 Throne. 2 to 9 Benches. 10 to 13 Large thrones

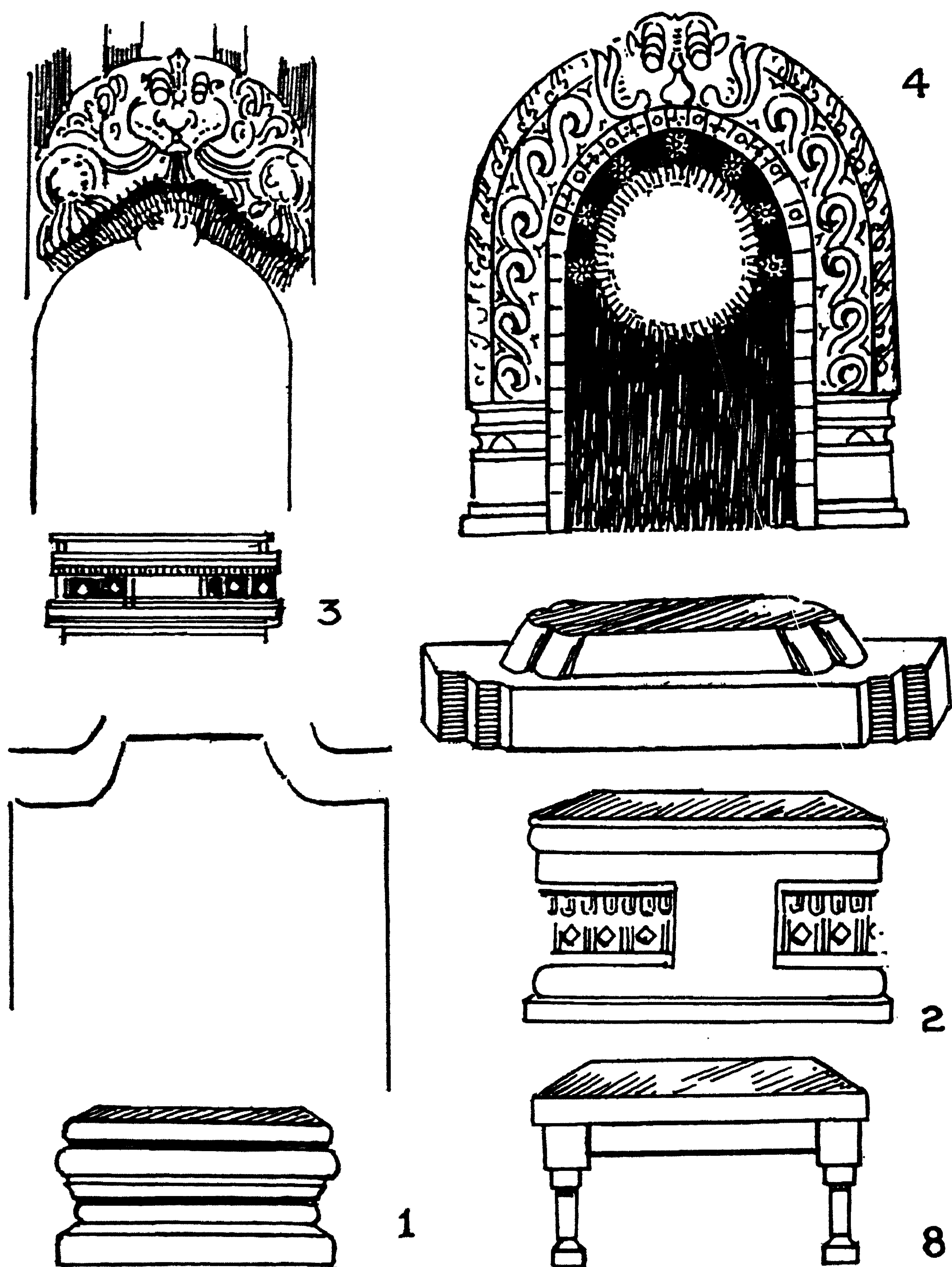
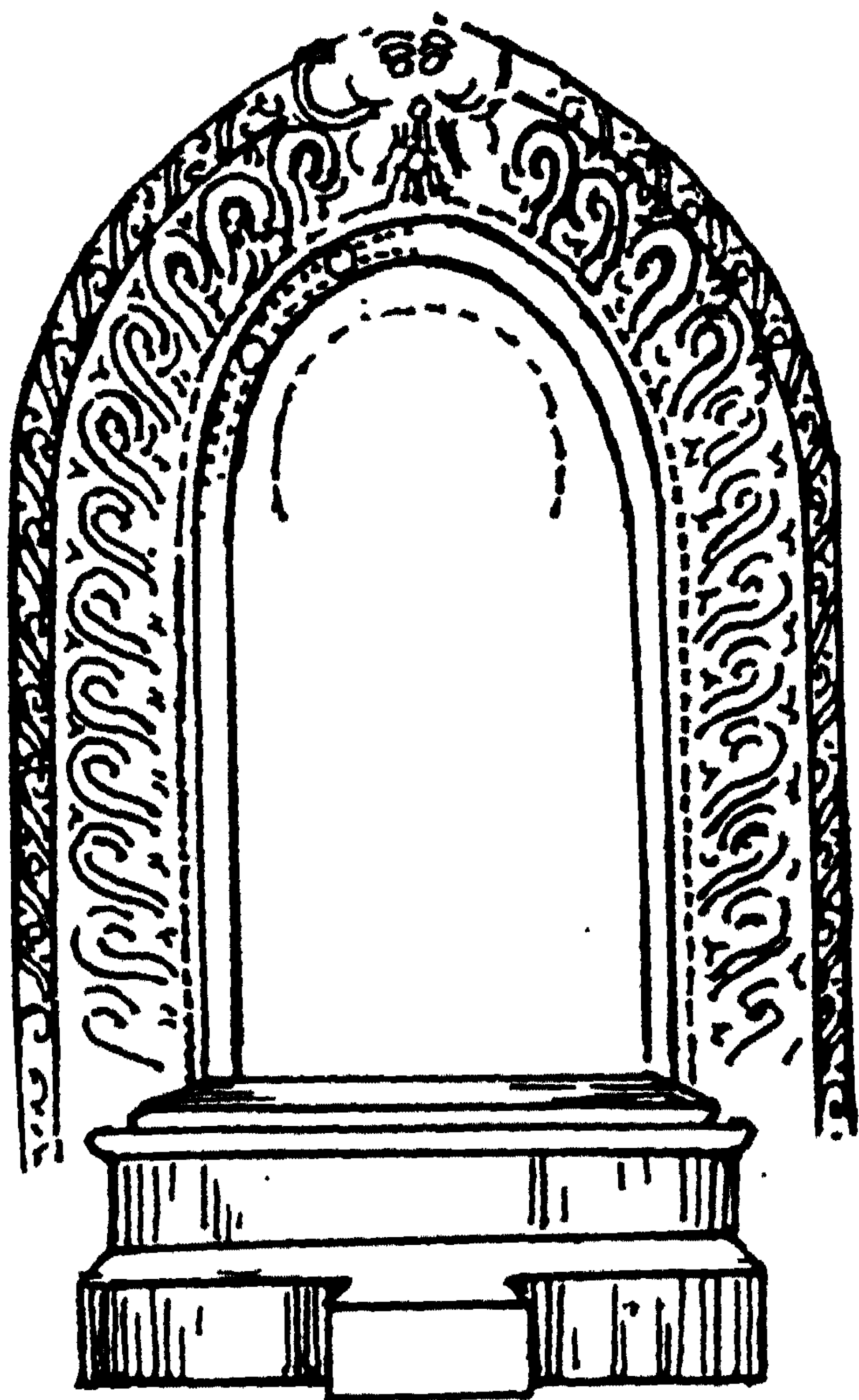
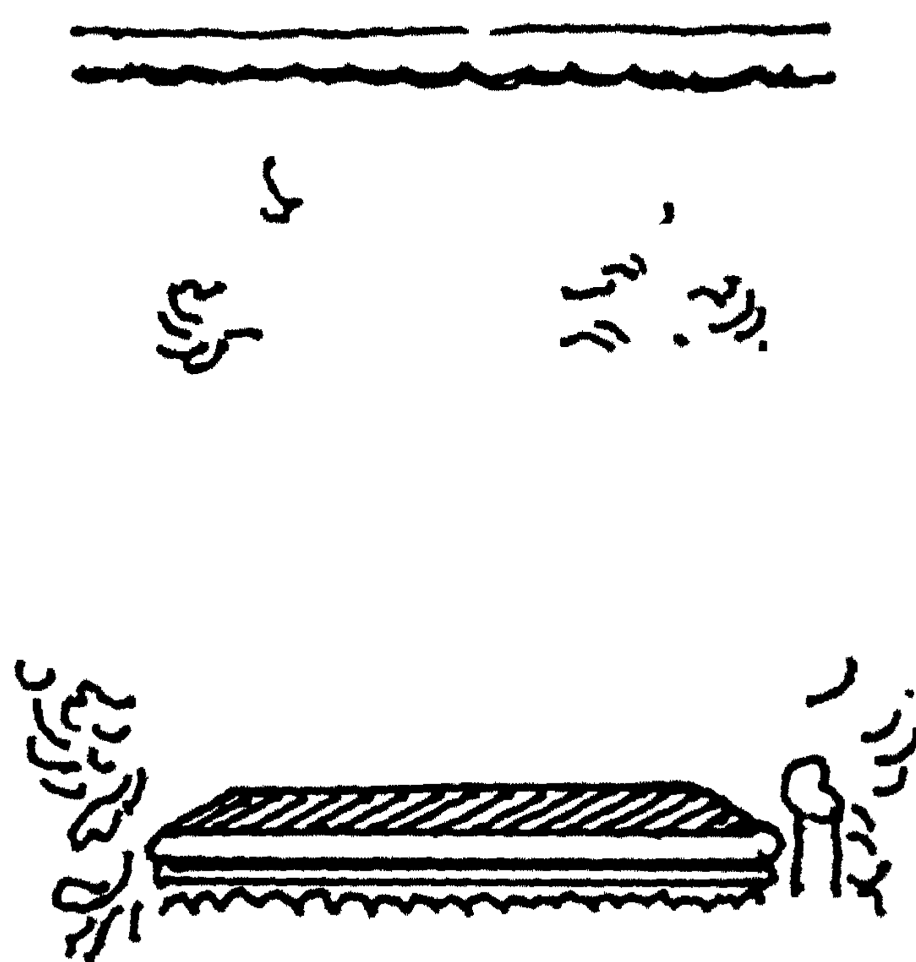
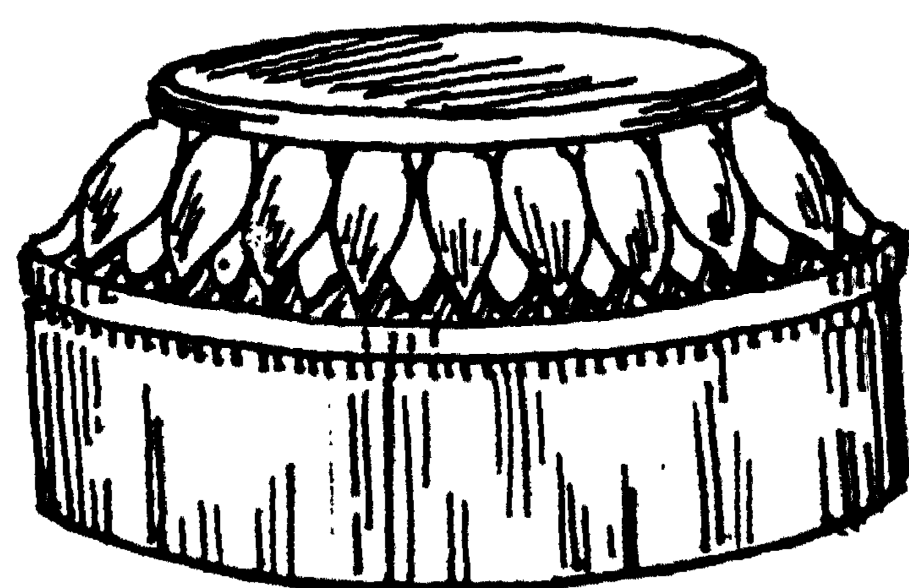
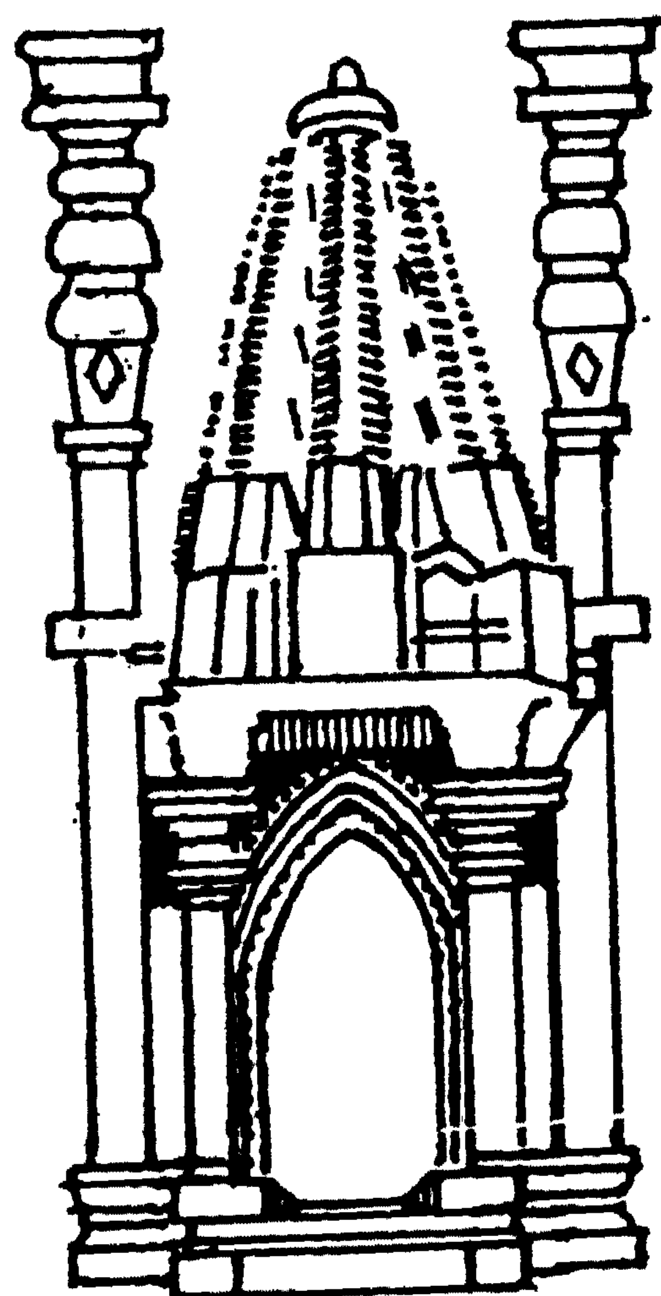


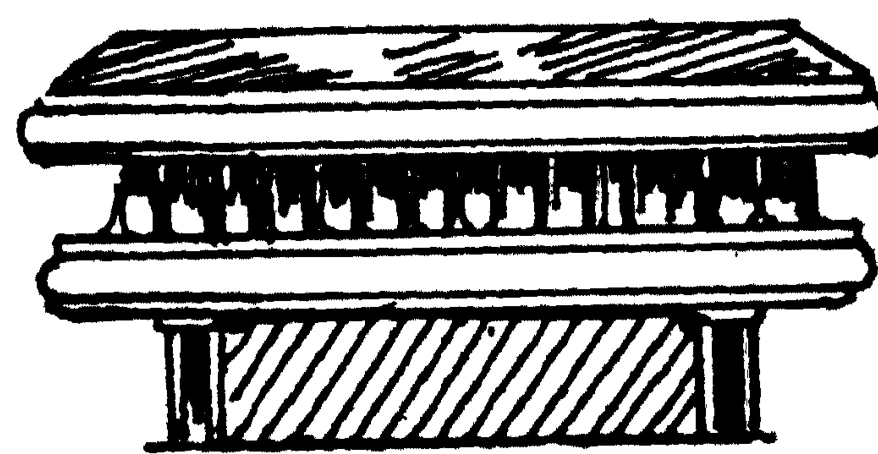
Fig. 3. Furniture - Hoysālā period. 1,2,3,4,8 .. Thrones

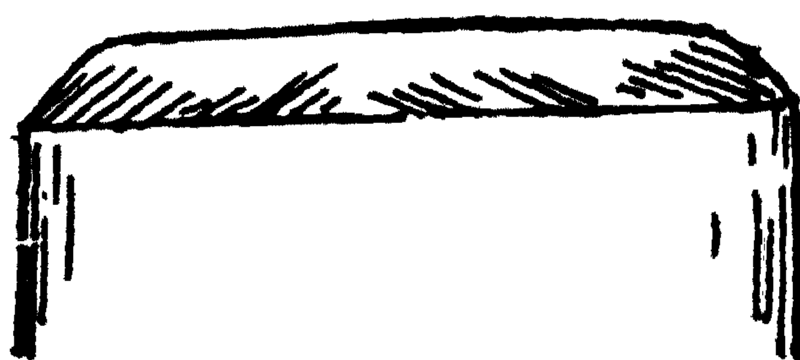












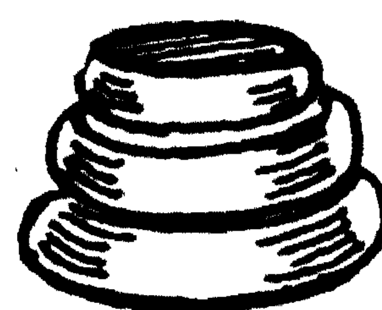


Fig. 4. Furniture - Hoysālā period 5,6,7,9,10,11 . Thrones

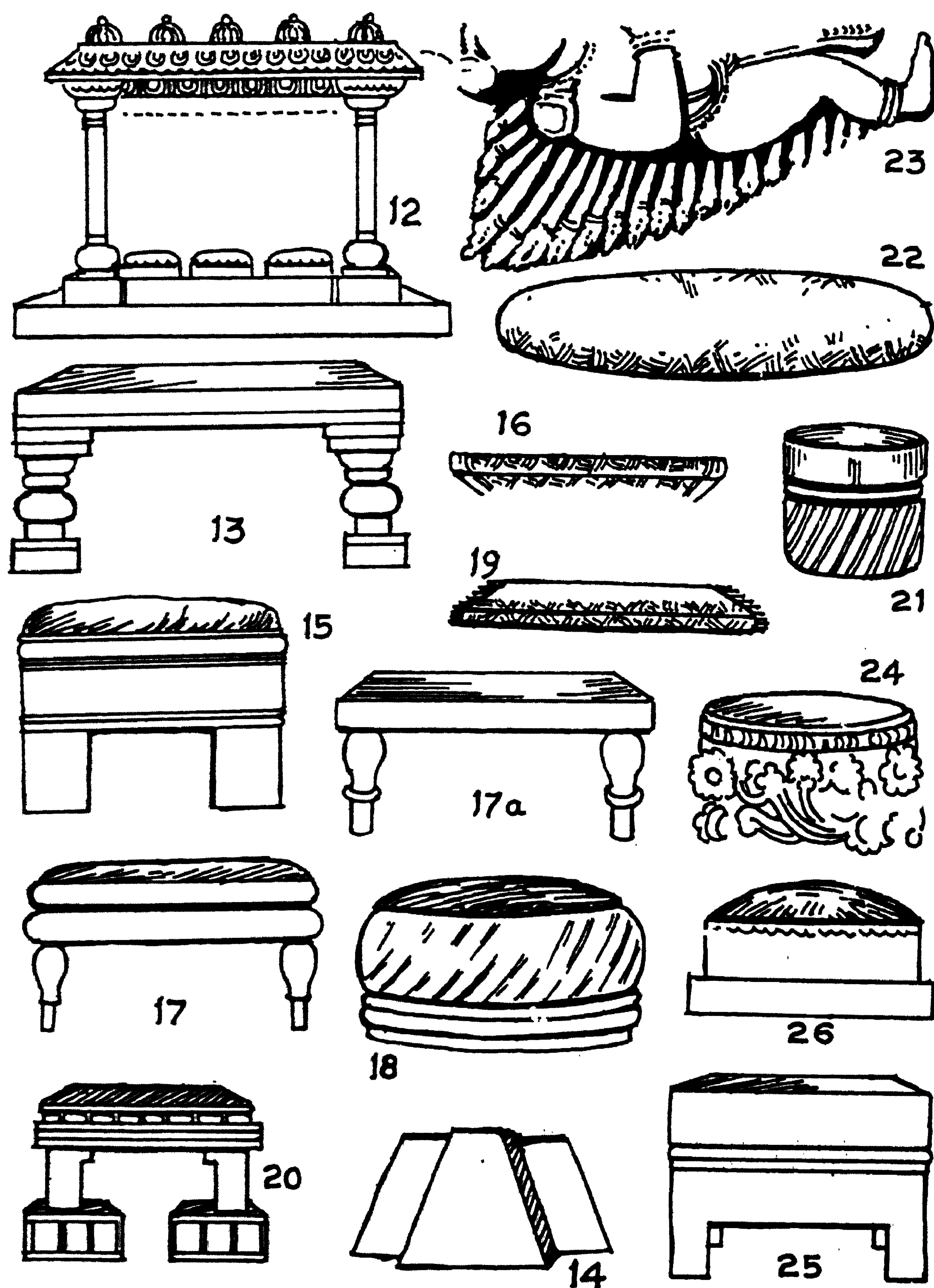


Fig. 5. Furniture - Hoysālā period 12 to 22 Thrones. 23 Arrow Bed. 24 to 26 Cane seats

variety of the preceding periods. The thrones, small and large, chairs with solid or animal legs, foot-stools circular or rectangular in shape, seats and bed-steads were among the furniture articles and remained as the items of the furniture of the affluent society while the commonality satisfied with sundry items like mats and mattresses etc. (*Fig. 1-5*)

Notes

1. *Indian Culture, Vol.II, No. 1, 67; Cf. Rāmāyaṇa, Sundarakāṇḍa IV, 41: In the Suśruta, the Rājavallabha and the Bhāvaprakāśa, we come across the use of Śayyāsana instead of Śayanāsana (Indian Culture, Vol. II, no. 1, 67; foot-note 2). The Śayyāsana- Lakṣaṇādhyaya (Ch. LXXVIII) of the Bṛhat Saṃhitā deals with furniture (A.M. Shastri, India as seen in the Bṛhat Saṃhitā of Varāhamihira, (Delhi, 1969), 250.*
2. *Mālavikāgni Mitra, 73, 87, 104; Parṇamañjusā, Tailamanjusā, Vāstramañjusā are the three kinds known to the period.*
3. *Siṃha-mūdrita-manoharāsanam! Kesari Lancitam tvatha manoharāsanam Mānasāra, XLV, 204, 206.*
4. *Mañca-Paryaṅka-PālyankaḥSanaḥ Palayaṇ-Komanca -Paryaṅka-Vṛṣi-Paryasti Kasuce iti miḍini (Amarakośa, 2, 3, 138).*
5. *Vaikhānasa Gṛhasūtra, 1216; Vinaya Text, ii, 3, miḍhi vin. text iii, 163 says that it is built against the outer wall of the house of hut made of hardened mud with two wooden legs in front. It is a bench used to sit or sleep on. In the Ṛgveda also the word proṣṭha to mean a bench has been mentioned. (VII. 5-8).*

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Writing-materials

MAMATA CHAUDHURI

The early human civilizations have urged from time to time to keep a record of their thought and have used some sort of writing-materials for this purpose.

During the Vedic period in India, learning spread verbally through words from the teacher to the disciple. Possibly reading and writing were not known at that time. With the discovery of scripts, the method of writing the verbal transmission of thought was gradually replaced by written records. The available materials used for writing, found in India, are generally of two types - hard and soft. Stone, metals, shells and earthenwares are examples of the former. On these, writings were carried out by engraving, embossing, painting and scratching, as the case may be; while the more or less soft materials are represented by wooden board (*pāṭi*), dust (*dhūli*), birch-bark (*bhūrja-patra*), palm-leaves (*tāḍa-patra*),leather (*ajīna*), cotton cloth (*kārpāsīka paṭa*) and paper. Engraving and embossing were effected by sharp instruments, while reed, chalk, stilus with colour or ink were employed for softer materials.

Engraving, Embossing, Painting and Scratching

(1) ***Stone*** : The earliest hard material used for writing was stone. Engravings on stone are everlasting. Such engravings were made on caves, smoothed or rough pillars, slabs, lids of vases, caskets, etc. These deal with official and private records, royal proclamations, land-grants, eulogies and memorials.

The usual process (Pandey, 1952, Pt.1, p. 76) of inscribing or engraving a stone consists of chiselling and polishing it by rubbing it with another stone having a smooth surface. Parallel lines were then drawn upon the surface of the polished stone by means of a piece of chalk. The writings were attempted within the parallel lines by a calligrapher with ink, chalk or dye; finally, the engraver engraved the letter. Any damage in the course of engraving was immediately filled up with some plastic materials.

(2) ***Metals*** : Of the varieties of metals like gold, silver, brass, bronze, iron, and tin, copper was most commonly used as the material to write on in ancient times.

An inscribed plate or piece of copper was called *tāmrapatra*, *tāmraśāsana*, *śāsanapatta* (plate for official decree), *dānapatra* (plate for land-grant), depending on the contents of the inscription. Different kinds of historical documents - for example, land-grants, official decrees, sacred books or literary works were engraved on copper, and in many cases, they have been preserved as specimens in different museums.

Two processes relating to the preparation of copper-plates, as evident from the historical records, are (i) by hammering, then engraving; (ii) by casting in a mould of sand.

Usually copper-plates were hammered into the required shape or size. (Fleat, 3(2), p. 172). Traces of such hammer-blows can easily be detected on many such copper-plates. The contents of the documents were first written with ink and were scratched by an expert-writer on the plate; letter were then incised with a chisel by a goldsmith or blacksmith. In certain cases, as can be found in the southern Indian records, the copper-plate was besmeared with a layer of a mud-like substance and the writing was done with a pointed piece of iron, which was again incised by a blacksmith with a fine instrument.

In another process the writing on copper-plate was done by casting in a mould of sand. A particular reference to the preparation of Sohgaura copper-plate (Fleet,1907, p.510) may be made here. The plate, instead of being hammered, was cast in a mould of sand, on which letters and emblems were previously scratched with a pointed instrument. These, therefore, appeared on the plate in relievo. The engraving of letters in some early epigraphs, like the Kalwan plate, was done by dots instead of continuous strokes. Incorrect letters of the record, in certain cases, were re-engraved after hammering; traces of earlier letters in such cases appear to be exhibited. With a view to preserving the document, rims of the plate were raised and thickened.

Generally, long documents engraved on two or more plates, were attached by copper-strings, passed through round holes in the plates.

Besides the common use of the copper-plate, a number of coins made of gold or silver have also been used as writing materials. They serve as sources of information regarding the foreign rulers in India such as the Greeks, the Śakas and the Parthians. Several written documents (Buhler, 1959, 1, p. 116) on brass, bronze, iron, tin, etc., have also been found.

(3) ***Shell*** : Specimens of some inscribed conch-shells have been discovered from the ruins of a Buddhist establishment at Salihundam in Srikakulam district of Andhra Pradesh (*Indian Archaeology*, 1953-54).

(4) ***Bricks, earthenwares, terracottas*** : A number of specimens of inscribed brick (*EI*, *XXX*, p.118 ff) have also been unearthed in different parts and preserved in archaeological museums. Earthen-wares (*Indian Archaeology*, 1955-56) and terracottas had also their use as materials for writing. Bricks or earthenwares were generally scratched before being dried or baked (*EI*, *XXX*,p.85 ff)

Use of Chalk, Reed and Stilus with Colour or Ink

(1) ***Wooden board*** : In ancient India (about the 5th century B.C.), the wooden board, known as *phalaka* (Buhler, 1959, 1, p. 93) was used. On it writings could be done by means of a piece of chalk (*pāṇḍu-lekha*). The method was used for educational purposes. In the beginning of the seventh century A.D., the term *pāṭi*, (Datta, 1935. 1, pp. 123-24), a non-Sanskritic word, represented a wooden board and the word *pātigaṇita* means the calculation made on the *pāṭi* (board).

In the work of Al-Bīrūnī (Sachau, 1910, 1, p. 182), the great Arabian scholar, it runs as follows : "They (i.e., the Hindus) use black tablets for the children in the schools and write upon them along the long side, not the broad side, writing with a white material from the left to the right".

The work of mathematical calculation was also called *dhūli- karma*, dust-work Datta, 1935, pt 1, pp. 123-124). The figures were written on a layer of dust spread on a board or on the ground. A piece of reed was used to write on the layer of the dust.

(2) ***Birch-bark (Bhūrja-patra)***: *Bhūrja* (*Baetula Bhojápattra*), the inner bark of the tree was the most popular material for writing manuscripts, specially in northern-western India (Buhler, p.112). Upon it writings were carried out with a reed pen and ink of special kind. This tree grew in abundance in the Himalayan region, from which it spread to other parts of the country. In the early Sanskrit texts, the bark has been described as spotted like the skin of an elephant.

Āl-Bīrūnī (Sachau, 1910, 1, p. 171), in his book, has given an account of its preparation, which is as follows: "In central and northern India, people use the bark of the *tuz* tree, one kind of which is used as a cover for bows. It is called *bhūrja*. They take a piece, one yard long, and as broad as the outstretched fingers of the hand, or somewhat less, and prepare it in various ways. They oil and polish it, so as to make it hard and smooth and then they write on it."

From the statement given above it appears that Āl-Bīrūnī himself was well acquainted with the locality where the birch- tree grew in abundance.

Āl-Bīrūnī (*Ibid*) also describes the making of a book with such barks in the following manner: "The proper order of the single leaves is marked by numbers. The whole book is wrapped up in a piece of cloth and fastened between two tablets of the same size. Such a book is called *puthi* (cf. *pusta*, *pustaka*). Their letters, and whatever else they have to write, they write on the bark of the *tuz* tree."

(3) ***Palm-leaves (tāḍa-patra)***: For writing manuscripts palm- leaves *tāḍa* or *tāla* (borassus flabelliformis) and *tāḍa* or *tāli* (*corypha umbraculifera* or *C. taliera*) were widely used, specially in southern India. About the use of palm-leaves for writing upon, Āl-Bīrūnī (*Ibid*) has observed, "The Hindus have, in the south of their country, a slender tree like the date and coconut palms, bearing edible fruits and leaves of the length of one yard and as broad as three fingers, one put beside the other. They call these leaves *tārī* (Sanskrit *tāli* or *tāḍi*) and write on them."

For writing manuscripts, the palm-leaves were at first dried, then soaked or boiled in water for a considerable time and dried again. After that the leaves were polished with conch or cowrie shell or a smooth piece of stone and, finally, cut into

the required size (Pandey, 1952, pt. 1, pp. 69-70; Buhler, p. 114). In the south, the letters on the leaves were incised with a stilus and were made black by the application of ink with lamp- black. At somewhat later date, these leaves were used for writing purpose with pen and ink all over India.

Leaves of the short length were punched in the middle of the one, while longer leaves were punched in the middle of both the ends. In this connection Āl-Bīrūnī (Sachau, 1. pp. 171-182) writes, "They bind a book of these leaves together by a cord on which they are arranged, the cord going through all the leaves by a hole in the middle of each... They write the title of a book at the end of it, not at the beginning."

Leather (*ajīna*) : While the parchment was commonly used as writing material in western Asia and Europe in early and medieval times, its use in India, if at all, was very rare. In some Buddhist texts, according to D'Alwis (Buhler, p. 114) skin is mentioned as a material used for writing upon. On this point Al- Biruni (Sachau pt. 1, p. 171) writes, "The Hindus are not in the habit of writing on hides, like the Greeks in ancient times."

Cloth : The Cotton cloth (Buhler, p. 112-*pata, kārpāsīka paṭa*) was also used as writing material in ancient India. Āl-Bīrūnī (Sachau, pt. 2, p. 11) has also stated that he was told about the existence of a pedigree of the Shāhī royal family of Kabul in the fortress of Nagarkot and this is said to have been written on silk.

Nearchos (4th century B.C.), an admiral of Alexander's fleet, has first mentioned that the Indians used to write letters on well-beaten cotton cloth (Buhler, p. 20). Cloth was made smooth and non-porous with the application of a thin layer of wheat or rice pulp on it. It was further polished with a conch-shell or stone after the same was dried and letters were written on it with black ink (Paṇdey, 1952, pt. 1, p. 72).

Paper: Paper, as a writing material, was hardly known in India before the eleventh century A.D., as there is no Sanskrit word available for paper. It is, however, suggested by some scholars (Bagchi, I, p. 287) that two words *Saya* and *Kakali* or *Kakari*, the Sanskritised forms from Chinese *tsie* or *kaghaz* occurring in the Sanskrit-Chinese lexicon of the 8th century A.D., mean paper. It is generally believed that the Chinese first invented paper in the first century A.D. and afterwards its use spread out rapidly to other countries. In the works of Al-Bīrūnī we find the following information. "It was in China that paper was first manufactured. Chinese prisoners introduced the fabrication of paper in Samarkand, and thereupon it was made in various places, so as to meet the existing want."

A paste made by rice or wheat pulp was applied on both sides of the paper sheets. These sheets were further polished with conch-shell or stone-roller, so that ink might, not be absorbed in the body of the paper and spread out on its surface (Sachau, pt. 1, p. 71).

Though there was difference regarding the preparation of pulp from different materials, yet it is known that generally the rags were thoroughly cleansed, boiled and beaten into a pulp with water to the consistency of cream. A finely woven wire sieve was dipped into the vat (*dāba*). A horizontal shaking motion was given to the sieve, which caused the fibres to felt or interlock, the water draining away through the fine holes in the sieve. The sheet was then placed between felt and subjected to

pressure. After drying, the paper was dipped in size (*maṇḍi*) to render it non-porous, and finally dried and smoothed it through roller under pressure. To size the paper and render it fit for ink, a glue, somewhat gelatinous, was first prepared in the vessel which contained this mixture, a rod was placed and a cleft stick used for holding the sheet of paper during the process of dipping. As soon as the paper had been saturated, it was withdrawn by gently rolling it round the stick which had been laid over the vessel. The sheet of paper was afterward hung to dry. It was then smoothened and polished by rubbing it on wood with the convex side of a chank-shell. Jute, *sunn*, *ambaree*, *moorve*, old sacks and finishing nets were also used as raw materials. Forbes Royle states that the fibrous parts of many lily and aloe-leafed plants have been converted into excellent paper in India; the fibres of tiliaceous, malvaceous and leguminous plants are employed for the same purpose. (Ghori and Rahman, 1966, pp. 133-49).

The other process of paper-making was like this (Ray, 1956, pp. 234-35). Here the raw materials were old clothes, old tents, the bark of certain shrubs and trees etc. After having been washed well and soaked in water for several days, these materials were beaten with a wooden hammer or *dhenkī*. The pulp was mixed with a little water in a lime-lined (*cūṇam*) reservoir, where the beating operation was also carried out. The workmen dipped their moulds into the reservoir, and the mixture, when lifted out, would become paper. It was then removed, and each sheet drawn through a second reservoir of water and then hung up to dry. A quantity of gum arabic was dissolved in water into which the beaten pulp was placed. The water in the second reservoir, through which the sheet were drawn, also contained gum in the form of a mucilage, as well as some alum dissolve in it. The moulds or forms used by the workmen were generally made of bamboo. The gum (gum arabic) was obtained as an exudation from a tree, known commonly as the *babool* tree.

Ink: The Sanskrit equivalents for the word 'ink' are *maṣi* (*maṣi*, *masī* or *maṣī*) and *melā*. The former is derived from the Sanskrit root *mas* (*himsavam*), which etymologically means "crushing or pounding," whereas the latter from *mel*, i.e. to mix (Bothlingk and Roth). It is therefore to be noted that the two words indicate the very techniques for the preparation of ink, i.e. by pounding and mixing the ingredients properly. That the ink was used for the purpose of writing is attested by accounts left by the Greek writers like Nearchos and Curtius (4th century B.C.), where it is stated that Indians wrote on paper and cotton cloth with ink (Pandey, p. 83). It is evident that for writing upon softer material like birch-bark, palm-leaves, cotton-cloth, paper, etc., stilus with ink was employed.

Writing-ink was generally of two types - durable and non- durable. Of these the first one was used for writing manuscripts and important documents and could not be washed away with water. This durable and ever-lasting ink (Ojha, p. 155) was prepared from lac, mixed with water, borax, *lodhra* (*Symplocos racemosa*) and lamp-black of sesamum, all boiled into a homogeneous mixture; while the ordinary one (Pandey, p. 84) was prepared with some kind of pulverised charcoal mixed with water, gum, sugar or with some other adhesives.

It is to be noted in this connection that the earliest record for the recipes for ink-making in India is found in the *Rasaratnākara* of Nitya Nātha Siddha (c.A.D.

1200). These recipes, mostly of vegetable substances, again, are equated with those of hair-dyes, as described in the *Nāvanitaka* (c. 2nd century A.D.).

Other coloured substances (Pandey, p. 84) like red, yellow, green, etc., were used also for writing and painting purposes. Of these, red-coloured preparation was made either from *alaktaka* (red dye) or vermilion, mixed with gum in water for writing and painting purposes. Besides, the powder of gold silver mixed with gum in boiling water was used for painting and artistic writings.

The instruments for writing on softer materials, as described in the Sanskrit texts, were *lekhani* (stilus, pencil), *tuli* (brush) (*Amara*, III. 10.32) *varṇaka* (instrument for writing a letter) (*Lalitavistāra*, ch.10), *varaṇa-vartika* (coloured pencil) (*Daśakumāra carita*, Ucchāsa, II).

Al-Bīrūnī's visit and his records on India testify quite a number of such writing materials in India and elsewhere.

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Leathercraft

R. SELVARANGAN

Introduction

From very early stage in the development of human race, utilization of animal skins for all kinds of essential purposes has continued without a break. In the earliest stages, the product crudely prepared from skin was not actually what we today know as leather currently employed. Chamoising with fats and oils, tanning with mineral salts and tanning with vegetable extracts were all established in prehistoric times. Evidence shows that it had reached a remarkable standard of perfection in the highly advanced cultural societies of Ur, Babylon, Egypt, Ancient India and China. As preparatory methods improved, so the scope of leather usage was widened until it embraced almost every sphere of human activity.

Not only in versatility has leather excelled as servant to mankind, but in adaptability also. New properties have constantly been imparted to leathers and as old uses faded out, new ones have taken their place.

Processing of Skins and Their uses

In many prehistoric sites all over India, flint scrapers have been discovered which were used to clean and prepare animal skins. Most probably the fleshing and the hair on the skin was removed and softened with fat and brain using flint scrapers.

The curved shapes of skin scrapers found on paleolithic sites suggests that they must have been laid over tree trunk to make the task easier, similar work is being done over a wooden beam now in the village tanning.

Evidences are there to indicate the animals and others whose skins were used during the ancient time in India, Asia, Europe and other places were oxen, calf, sheep, goat, lion, panther, gazelle, cheetah, antelope, leopard, camel, hippopotamus, dog, ibex, deer, cat, rabbit, hyena, wolf, bison, ass, pig, donkey, bear, jackal, seal, otter, horse, snake, lizard etc. The tanning materials used are Gall nuts, Acacia Arabica, pomegranate, oak, spruce, pine, sumac, amla, asan, myrab,

alum, vinegar, etc. and also other materials like, the insect kermes, flour, fermented vegetable matter, wine, beer, milk, salt, curd, cow dung, fermented fleshing, urine etc were also used in the ancient tanning processes. The usual mechanical operations are handling, beating, beaming, pulling, staking, stretching on wooden frame for drying, polishing by stone etc.

In the tanning process, the hides and skins are soaked in water, treated with lime and fermented liquor in pre-tanning processes, tanned using vegetable tanning materials, alum, oil and fats and coloured and sometimes polished. Vegetable oils and fats were used to make heavy and tough leathers. Light leathers were made with alum alone or in combination with vegetable and oiling and also by oil (Chamois) tanning. Parchments are prepared by scraping off the hair with some pretreatment or after sweating.

These leathers were used in ancient times to make articles for defence purposes - mainly moulded or scaled - protective covering for head, body, leg and feet for the warrior and his mate, shield, scabbard, saddles, horse, trappings, war tents, boats, musical drums, dhundubi, writing parchment, containers to stock water, liquids and solids, drinking cups, and for civil uses as cap, head clothes, clothing, gloves, chappals, sandals, shoes, boots, boxes, containers, drinking cups, percushion musical instruments (eg. Dhundubi), writing parchment, shadow parchment puppets, parchment leaf for beating gold into thin film, sound box for musical instrument, mattress, cushion leather chairs, curtain, aprons, sweat bands, wall covering, balls for games, leather cases, dog collar, leases, whips, thongs, and twisted ropes of varying diameter and length, window panes, doors, thongs, tent, boat, leather buckets, water sal, bellows, etc.

Examples of really ancient leather is very rare because it is a perishable commodity. Skin is preserved in the dry climate as in the tombs in Egypt and in saltish water as leather scrolls of the Dead Sea and in frozen places as that of the leather in the frozen wastes in Central Asia. Probably more actual articles of leather survived in these places than any where else but this is not to say that similar leather articles were not in use elsewhere particularly in India. Even most of the leather articles of recent past are to be considered more or less the replica of the ancient ones like the body armour, shield, scabbard, containers, garments, caps, boxes, chappals, sandals, shoes etc.

The oldest leather was found by the Tunisian researcher E. Schiaparelli during excavations at the Upper Egyptian settlements, Ghebelen. At the same place he found a real tannery and the tanning material used in tanning - Acacia nilotica containing 31% tannin - a tannin species similar to the Bābul of (acacia arabica) of India. Acacia nilotica is available even today in Sudan, the neighbouring country of Egypt where the author of the article analysed the pod of the species and found to contain 41% of tannin - a very good tanning material - nothing to outbeat it even today (*Fig. 1*).

The leather was produced in North India using *bābul*, alum and shellac to make *Nari* leather which was used to make leather garments shoes and balls. The use of pomegranate rind in tanning and dyeing is of ancient origin in Kashmir and it is found to be followed even today. *Dhāva* leaves, *Āmlā* leaves etc. similar to Sumac find a place for mild tanning and colouring in India.

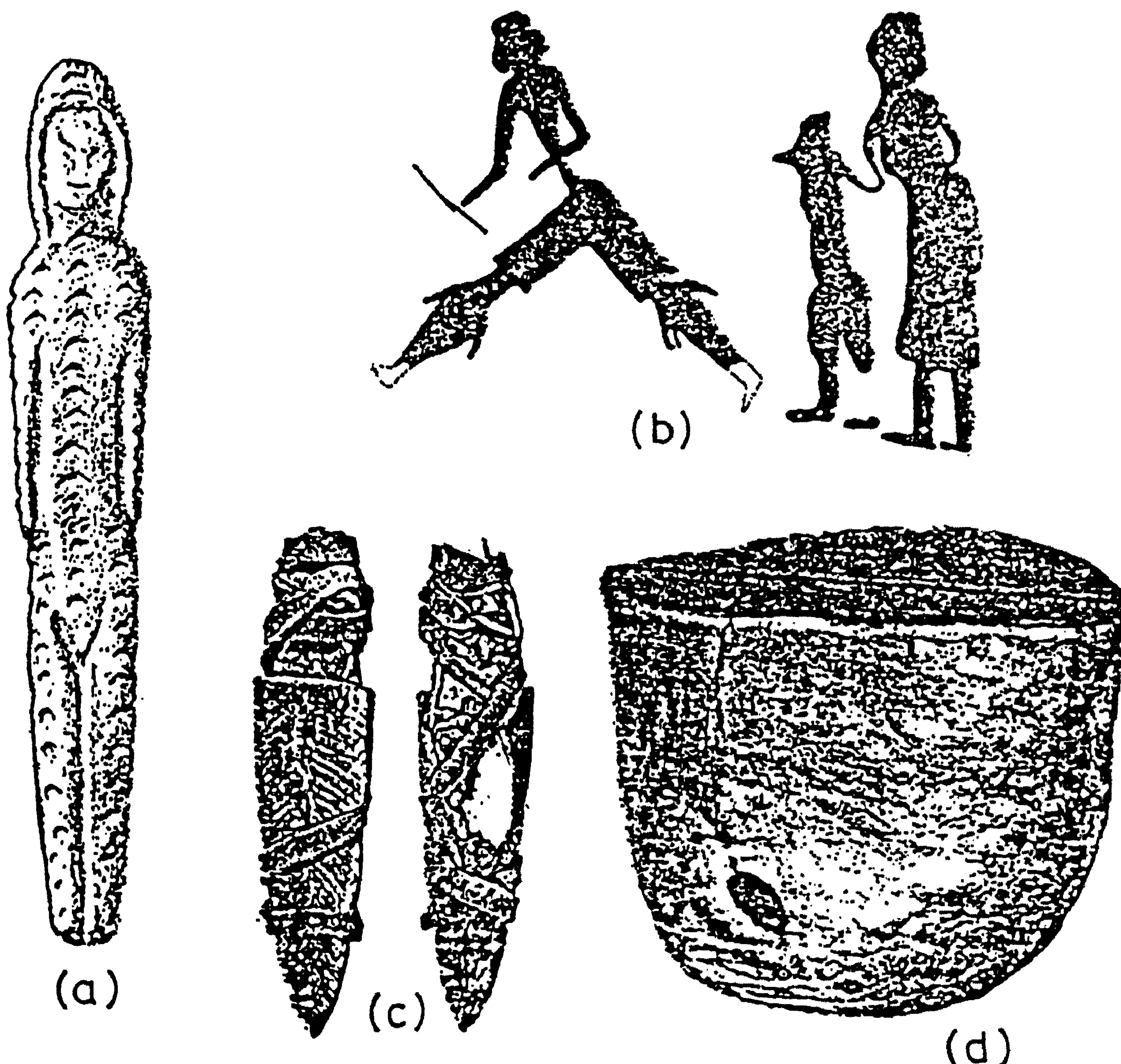


Fig. 1. Pre-historic leathercraft a) Ivory Statute from Buryat, Siberia, b) After paintings in Spanish Levant caves, c) Found near Hamburg, coutesy Stade museum, d) Leather board on loan to the Museum of Leather craft

Indians used mainly *bābul* pods and bark in vegatable tanning especially in a bag form. Bag tanning is a technique wherein the hides and skins are stitched into a bag form and bark with infusion is kept inside the bag so that the tanning infusion will percolate through the thickness of the hides and skins rapidly and evenly effecting a very good vegetable tannage. Also made leather using alum and oil tannages alone and in combination with vegetable. Chrome tanning was not in use in ancient time since it is a recent origin (end of nineteenth century). Malaya, Japan, and India made parchment for making puppets for shadow shows and also India made parchment to use as a sheet for writing as well as musical instruments as in Persia, Babylon, Egypt, etc. Tartar knew how to make leather flasks in grotesque forms using 'boiled leather'. Similar leather bottles were also made in India. Alum tanned soft leather was used to make the red leather gloves presented to an official depicted wearing these in tomb painting from Tel-el, Armrna in Egypt dated about 1370 B.C. Similar leather was also produced in India.

Early Indian Variety

The Indus Valley people domesticated humped bull, sheep, camel, elephant, buffalo, goat, cow etc. The valley engravings on seals show what perfection had been attained in the breed of these magnificent creatures which were worshipped in India from time immemorial. They were fond of hunting as on certain Seal representation of men shooting a wild goat and large antelope with bows and arrows. The art of writing was known to them as found in Seals and may be on parchment, too. But the condition in the valley was so devastating that we cannot expect the relics of the leather craft to survive for us to witness.

India being a tropical country, the use of leather was much less for footwear among the working class who were poor and illiterate and often barred from wearing by the Caste Hindus from later Vedic period. However, the demand for a variety of footwear from Kṣatrīya and Vaiśya were quite high. The demand from the priestly community was meagre and their necessity was fulfilled by using cheap and simple leather as well as wooden sandals.

Major amount of leather were utilized for defence and agricultural purposes. Most of the development in leathercraft might have taken place only through the invaders and the tradesmen and not much by the craftsmen themselves since they were illiterate.

In the time of *Ṛgveda*, Indra was said to have produced rain by piercing *masak* (skin water bag). In the Laws of Manu, the peculiar form of *dṛti* (skin water bag) with the four feet left intact is pointed out. According to the law books of Sankhya that water was declared pure which was kept in older leather bottles. The use of such word as *carmanta*, *carmapath*, *vastra*, *casabandha*, etc. in older Sanskrit work indicates that straps, bands, and strings of leather were in common use and sails were also made of leather.

The *Ṛgveda* often refers to the quiver and the gauntlet. Megasthenes mentions about the bridle. When it is said that an Indian by springing forward in front of a horse, can check his speed and hold him back, this is not true of all Indians but only of those trained from boyhood to manage horses for it is a practice with them to control their horses with bit and bridle, and to make them move at a measured pace and in straight course.

Harness and chariot in which leather was used are also mentioned in the *Ṛgveda*. Here are some verses 'The Pairaj, the kingdom of Kashirat rub down the high spirited steed, decorated with golden trappings' 'Harness with traces to thy car thy long manned ruddy steeds to the sacrifices'. 'Ascend Aswins, your sky touching chariot with golden seat and golden reins. Golden is its supporting shaft, golden the axle, both golden the wheels'. Shoes, for example are mentioned in the code of Manu as a suitable gift for a Guru.

The *Ṛgveda* refers to the many uses of leather including chariot, rein and whips, bow strings, wrist guards, slings etc. Chariots are described in detail with leather bodies mounted on a light wooden frame, the axles were attached by leather straps 'As with the leather thong they bind the chariot yoke to hold it fast and crossing a river, so let your wave bear up the pins and ye oh water, spare the thongs...'. Examples of chariot such as these have been found in a number of places, including

Egypt which was ruled by Persian pharaohs between the 6th and 4th century B.C. The floor of Tutankhamens's chariot was made of interlaced leather thongs. Raw and tanned hides and skins were also used as tyres for chariot. This indicates the art of tanning and manufacturing of leather products are more inter-related among the ancient civilization.

In the *Rāmāyaṇa*, the leather industry was one of the many other thriving industries of the day. The Ayodhyakāṇḍa tells us of the inhabitants who went out with Bharat seeking after Rama including 'curriers', musical instrument makers and armourers.

In Manu and the *Mahābhārata*, the slippers are mentioned. The *Viṣṇu Purāṇa* recommends the use of shoes to protect the feet.

The art of utilizing the hides and skins especially that of game animals to make stuffed life-like animals is known as taxi dermy. Sometimes head alone is preferred. Sometimes the skin without hair or fur on alone is processed. The human being wearing the full skin with head, like the one of the tiger, bear, guerilla etc to dramatise a scene in the drama, to attack enemies and scare people as well as to entertain them, might have been very common during the ancient time. The various humans in animal form depicted in mythological stories may be even human beings camouflaged with animal skin.

In India, the place of life stock resources in the Agriculture economy is well known. In the early period of Indian civilization cattle were considered to be one of the main sources of wealth. A further illustration is found on this aspect in the *Arthaśāstra* which describes about cattle feeding and in the *Mahābhārata*, a mention has been made on the cattle census and pedigree register.

Carmār (*cāmar*) tanned the '*carmax*' (the covering of animals) and handed over to *cakkilīya* to stitch into shoes, *aṅgustra* (a protective cover for thumb of bow), *vastra* (garment), *kavasa* (shield), kuppies (bottles), *kavalai* to draw water sources for irrigation, etc. These are no doubt leather products of ancient India.

Leather Garments

In ancient times the people used to offer to their gods, gurus, the things that they considered very essential and valuable. Under the same custom, people in India offered leather *vastra* to their gods, leather '*āsana*' (seat), and sandals to gurus. Leather *pādukā* (wear for patham) to Lord Venkaṭeswara in Thirupathi (A.P.), Lord Ranganatha in Srirangam, (Tamil Nadu), Lord Hanuman in Shimoga, (Karnataka) were offered from very ancient time by the devotees - the shoe makers.

Greeks, Romans, Egyptians, Persians and others had tanneries and leather work with whom India had direct contact from ancient time and it was aware of this leather craft besides its own innovations.

The climatic condition in South India is quite tropical, ancient Tamil literature indicates that the ancient Tamil were not wearing only leather clothes but also from leaves 'Thazhi uddai.' and that of bark 'Mara uddai.' They were also eating meat of goat, cow, elephant, deer etc. The covering of the animals, not eatable, were used to make leather and leather articles. Their gods were also attired with the skins of

deer, tiger etc. These skins were also used to make seat to sit on or sleep comfortably with the effect of good air cushion. Recently it was noticed and used fur skin as bedsheet for patient with severe burns. The ancient Tamil used chest gear covered with tiger skin. They used protective covering known as 'Kavasam' made of moulded leather, elephant hide and layers of other hides pasted together to cover separately, head, chest, hand, finger, leg and foot.

Leather garments *Nina Cattai* (leather shirt) were worn. Footwear was known as *Thol adi* (leather sandal). In a place known as Athiraipakkam,50 Km from Madras,found on excavation,the stone tools of Neolithic man used for scraping or setting skins and making holes.There are fleeting references in Sangam Tamil Classics which were brought out in the early century of Christian era They contain evidence to the prevalence of the customs of wearing sandals, garments and 'Kavásam'.The word used in *Perum-ban-Arun-padai to denote sandal* is *Adipatai Aranam* (sandal ware).*Cilappathikaram* refers shoemakers as *Thol Thunnüner* (skin sticher).

The sun god, Mitra, is also depicted wearing white half boot when riding. The god's costume is almost exactly like those of the Sasanian and Parthian kings with a tunic clasped by a broad leather belt, trouser high boots. He is also depicted in a white marble statue of 7th and 8th centuries A.D. where he is clearly wearing half length boots with buttons or perhaps a decorative trim up the middle and around the tops. Another earlier relief of the second century A.D. from Hatra portrays the same kind of scene in which the god holds the hilt of a sword in its leather scabbard, and a leash restraining three lions. Similar descriptions may hold good for the Suriya of the Aryans who invaded India during the same period. The sculpture of Suriya in Delhi National Museum depicted as wearing half boot. The Hindu God, Lord Shiva is depicted wearing tiger skin and having a percussion instrument known as 'Uddukai' or 'Damar in his hand'. A statue of Buddha with sandals (Kolhapuri type) is found in Egmore Museum, Madras.

Indo-Scythian Kuṣāns in the first century B.C. penetrated north eastern Iran as far as the Caspian sea and ruled in what is now known as Afghanistan. Sir Aurel Stein, the famous British Archaeologist excavating in the Takla Makan desert of Chinese Turkistan, found vast quantities of documents on wood and leather, preserved almost like new and written in Kharosthi, a first-century A.D.Indian script of the Kusans. While two headless but inscribed statues of King Kaniska (2nd century A.D.) depict this Kuṣān monarch wearing a belted tunic and what appears to be a cloak but might be a full skirted coat slung over the shoulders; he has baggy riding trousers gathered at the ankle and tied under his boots by straps. One statue was found by the fire temple constructed by Kaniṣka at Surkh Kotal in northern Afghanistan, Kabul Museum. The other was found at Mathura in India and both portray a costume that obviously developed from the Scythians and Parthians and was the forerunner of the typical Sassanian riding dress. At Bamian, the famous valley of the Buddha, a number of the painted frescoes on the walls and ceilings of the Buddhist cave monasteries depict figures wearing typically Sassanian costume.

The Indian king well protected went to war on elephant or chariot well protected with body guards, having his regiment of warriors in front marching head in chariot,

elephant, horse and foot respectively. As described earlier, each and everyone and the animals in the battle field were all well protected in many ways with leather products brought out by skilled leather craftsmen working day and night intensively and ceaselessly, year after year for centuries in the ancient time. King is followed probably by the supplier of leather tent, boat, leather spares, leather thongs and twisted rope of varying thickness and length, leather mats, seats, curtains, leather dresses to wear in mufty, shoes etc besides other non-leather items.

Demand from king on leather craftsmen was very high during war and peace time. During peace time, they had to meet the demand of various leather articles for day to day uses like shoes, clothes, caps, bags, boxes, containers, cups, buckets, *kavalai* (Thol sal), straps, ropes, belts, etc.

Indian leather craftsmen were kept busy all the time to make leather products for defence uses, civil uses and irrigation and cottage industries' uses (handloom, oil seed grinding, blacksmith, goldsmith, drum and puppet making, bookbinding, etc.)

The scales of ant-eater are a special growth of animal skin and provide a natural armour and were used in India, Persia and other countries made a form of Camellias armour with the backing of leather or cloth. Other scales used for the armour in India are fish scales, thick leather piece of 1-2" sq pieces overlapping one above the other and metal scales. This kind of leather pieces are kept in the National Museum, New Delhi. The fish scale armour is in the Patna Museum. Warriors and horses wearing such armour are depicted in Persian sculptures. Body armour covered with scales of untanned hide and with hair remaining is kept in German Leather Museum, Offenbach (*Fig. 2*).

The sculptures of Kaniṣka found in Mathura is depicted as wearing leather shoe with corrugation, sword with leather sheath and leather overcoat. We could not say anything about the head gear since the head is missing.

In the *Mahābhārata* the shield was termed as *Carman*. It was made generally of leather adorned with figures or a simple tiger skin or bear skin worn over a body besides the brazen breast plate served as a shield. The shields made of bull hide are highly spoken of. When Duryodhana entered the battle field on an armoured elephant he was followed by among other soldiers, hundred of shield-men (or shield bearers) and archers.

Many of the styles of riding boots and sandals still survive today demonstrating that little has changed during the past two thousand years and more, so are our utilization of the most versatile and decorative of all natural resources is concerned. The earliest type of footwear used by primitive man was a type of moccasin which was made from single piece of leather gathered around the ankle by leather thong threaded through slot and it was crudely fashioned and it almost looked like a bag. Part of Hittite panel of not less than 1200 B.C. depicts a full shoe developed by them.

Leather Sandal

A leather sandal took the main role in life according to *Kauṭilya* 4th century B.C. and therein he says 'Smearing sandals made of camel hide with the fat of the owl

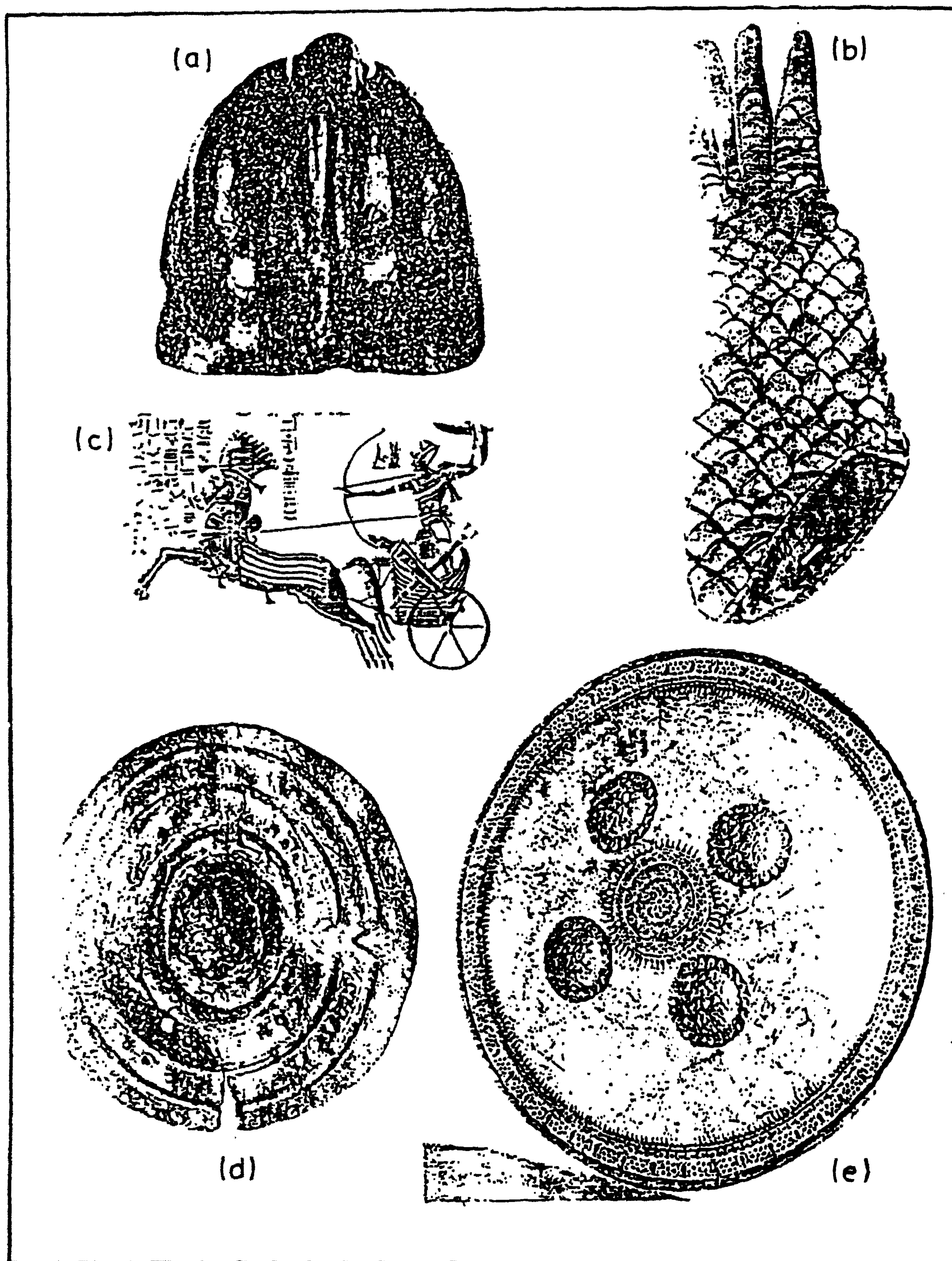


Fig.2. Ancient leathercraft for defence use a) Armour for horse arment b) Armour gauntlet for the right hand and forearm c) Egyptian war chariot d) & (e) Leather shield

and the vulture, covering them with leaves of the banyan tree, one walks fifty yojanas without being fatigued'. We know, at present, that it is very comfortable to walk a long distance with shoes instead of bare footed. According to the Hindu caste system, *cāmār* is the tanner and *mocī*, the shoe maker. Manu Smriti (first century B.C.) mentions that a pair of leather sandals was a suitable gift for a guru. In the 'Mitra records' Toy Cart of Sudraka (first century B.C.) a lady with muslin attire with a pair of leather slippers showing that in ancient time as, at present, woman of the town were in the habit of wearing shoes. The Visnu Purana recommends the use of shoes when walking out of the house, particularly in thorny place and on hot sand. The sun god presented a pair of chappals and umbrella to Jamadagni for protection against the hot sun.

Panini, the grammarian (350 B.C.) speaks of the *anūpadina* - a variety of boots. Paramananda (57 B.C.) also mentions it in his *Amarkośamālā*. The use of hog skin for the preparation of shoes has also been mentioned in the Vedas. Arians says in 2000 B.C., 'They, the Indians wore shoes made of white leather (probably alum tanned) and they are elaborately trimmed while the shoes are variegated and made of great thickness to make the wearer seem much taller'.

The footwear worn by Kannappa Nayanar of 10th century A.D. exhibited in the Tanjore Art Gallery appears to have been made of leather. Some miniatures also show the practice of wearing footwear by the ancient Indian rulers. The disciple Raidas, a shoe maker, used to present to all wandering ascetics new shoes. Shoes were offered not only to sadhus but also to gods. Different patterns of Farmers' shoe like the shepherd shoe, Okhai shoe etc. are available throughout Saurashtra and Kutch regions. Made by the native artisans, these are primarily used by the peasants and other village folks and normally not worn by the educated class of people. Made from the vegetable tanned leather, some varieties are usually heavy and sturdy; some are extremely light and soft. The leather soles and heels are made with several layers and laced with leather thongs tucked with horse shoes and other iron pieces and nails, the sole and heels are noticeably strong to withstand wear and tear. Some variety is plain and simple, but some are heavily adorned with eyelets, tinsels, coloured threads.

Generally the shoes are not marked for the right or the left which also indicates these are very ancient. The toes are sometimes upturned. Velvet upper with leather lining is used for ladies' shoes. The marriage shoes are admirably ornamented.

Kolhapuri chappal is a model footwear of Indian tradition (*Fig 3*). Its name and fame have gained popularity even across the oceans. The lightness, softness and the walking comforts are the characteristics of Kolhapuri. This is also known as '*Attani*' and '*Nippam*' chappal as the ancestors of Kolhapuri chappal makers are said to have hailed from Attani and Nippani in Mysore. Finely decorated with braided laces, the slipper is handmade from bark tanned leather. The sole is laced with leather thongs, the straps of the chappal are attractively made and perforated with hand tools.

Maharashtra is also the home for another Indian traditional footwear called '*Horāci*' chappal. The upper of this type of slipper is made from hand woven laces.

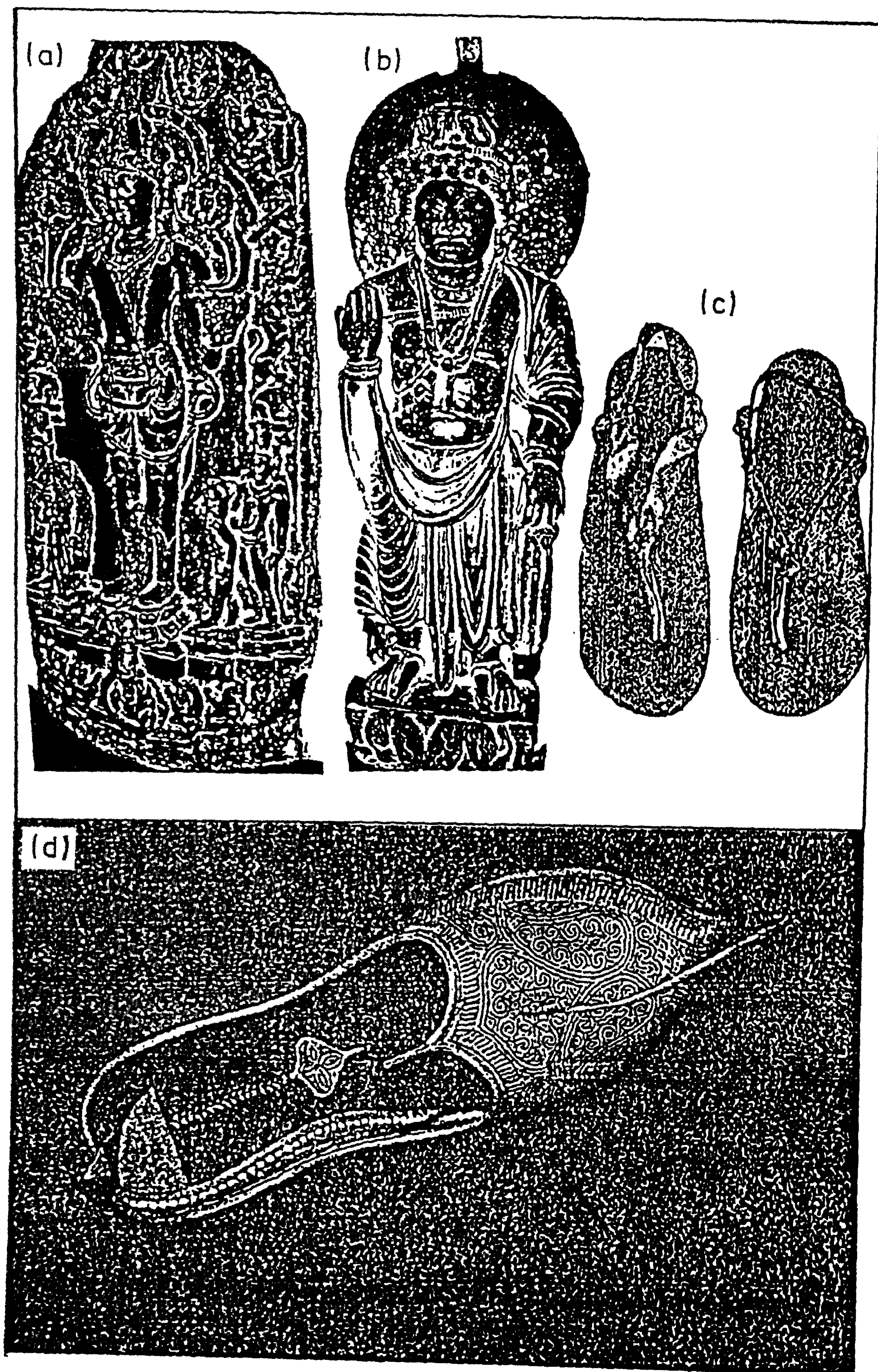


Fig.3. Ancient leathercraft for footwear a) Sūrya's Boot (Delhi National Museum), b) Buddha's Sandal(Eqmore Museum), c) Leather Sandal in Egyptian Tomb (Coutesy Metropolitan Museum of Art) d) Carftsmanship from Punjab

The fancy form of Chamba sandal of Himachal is handed down for centuries. The noticeable features of the Chamba sandal are the colourful hand embroidery; and the upturned toe is an elongated strap skillfully incorporated into the woven vamp. The age old pattern of Kabul sandal of the north western frontier and Punjab have some similarities in construction.

Ladies slipper (*juti*) from white leather without the mark for the right or left foot are found in Punjab and the neighbouring states. The hand embroidery work of the footwear in white silk are similar to those of the Punjab 'phulkārī' techniques.

The toes of the closed type slippers are broad somewhat round and narrow. The open type is flat.

It is difficult to reckon how old the pattern of '*nāgrā juti*' is. The exquisite needle work in gold and silver threads of the *juti* for both men and woman reflects the Persian style. The gilt ornamental slipper is also known as the bridal shoe '*Zari juti*' etc. A photograph of excellent embroidered *juti* has been recorded by John Waterer. The artistic footwear was so fascinating that the native crafts were patronised by the rulers and rich families of India. The artisans flourished mainly in and around Delhi, Rajasthan and Punjab and other northern states. Light in weight, hand dyed and hand stitched, the designs of *nāgrā* are sometimes plain, sometimes decorated with spangles, tinsels and eyelets. '*Nari juti*' (slipper for woman) like other '*nāgrā*' pattern, does not mark for right or left foot as it was common in the ancient time in India and other countries.

Leather Boats/Boxes

Magasthenese describes in his book on India, the Magadha empire and Candra Gupta Maurya. *Arthaśāstra* gives a great deal of information regarding the shipping in those days. Candra Gupta maintained a large number of boats and ships for the purpose of trades and also for checking pirates. During the time of Cyprus, the Great, the founder of the Archaemenian (550-350 B.C.), the leather boat even to a capacity of 14 tons were made in Armenia and plied down the river Euphrates by two men carrying wine as principal cargo and, at least, one donkey to carry the leathers of the dismantled boat back to Armenia for reuse. In 512 B.C., the Archaemenian armies crossed the Bosphores by a bridge of leather boats. Saint Brenden lived during A.D. 489-583 sailed using leather on several voyages along the west coast of Ireland. Tim Severin, the author of the book 'The Brenden Voyage' published in 1978, re-enacted the scene in 1976-77 and proved such a voyage was feasible. Fine white wood or the native Irish Ash made Brenden's lattice frame. Nearly two miles of leather thongs was used to hand lash 1600 joints into Brenden's frame work. The 49 vegetable tanned with Oak bark ox hides (4′ × 3.5′ each) were used and stitched together to cover the frame. Buckets of wool grease was used and painted over the hull to protect the thongs, timber and the leather. Brenden started from Ireland on May 17, 1976 and reached Newfound Land on June 26, 1977 via Faroes islands, Iceland, Greenland, sailing 4500 miles. A leather boat that some had feared would disintegrate in the first gale had successfully crossed the Atlantic. There was no longer any practical objection to the idea that the Irish monks might have sailed in leather boats to North America before the Norseman and long before Columbus.

Alexander (329 B.C.) crossed Hindukush mountains and Indus river in (328 B.C.) and was welcomed by Ambhi and fought against Porus. Shield in the 4th century B.C. was described in connection with the body armour of Porus which had bewildered the Greek historians. Almost all the Greek warriors were carrying shield which was tied on their back. Similarly the Indian foot soldiers were having shield on their person while the charioteers had kept them inside the chariot. Fully armoured, Porus rode a tall and formidable elephant which in turn, was also well protected.

Alexander crossed the river probably using his portable tents as boat, 23 miles up in a rainy night with his 12000 men and attacked. Elephants turned bad due to the heavy showers of arrow from behind. The slippery state of the ground prevented the Indian infantry from making full use of their formidable bows which they were customed to draw after resting one end upon the earth. Again due to the muddy ground, the heavy wheeled chariot could not move easily and many of these got fixed in the mud. In the confusion Porus lost control over the army and himself was taken prisoner. Alexander defeated Porus and his men because of his ingenuity in converting the tent into boat and crossing the river swiftly which could not be visualised in time by Porus. Alexander and his men might have contributed considerably during their stay in India for the development of leathercraft for defence purposes. Domesticated animals from the land he conquered were used by his army for meat and skins. The skins or the hides might have been processed by improved methods wherever he was camping with the available local materials and men to make processed parchment and leather products especially for defence uses.

Leather boat had been in use to sail across the sea, river and lake and also used as a small fishing boat. The small boat can be carried on one's head and found even to-day at Hoegnekal and other river sites where there are no bridges.

Marco Polo, the Venetian traveller mentions about the dressing of great number of skins of various kinds (goat, ox, buffalo, unicorn, and other animals) in the province of Gujarat in India. He also observed beautiful mats in red and blue leather, exquisitively inlaid with figures of birds and beasts and skilfully embroidered with gold and silver.

The Arabs, according to Herodotus, had cow hides and other skins stitched together to form a pipe long enough to reach from the river Corys to the desert route in three separate places and then filled them with water for the troops. Another version of supplying the troops with water was that of filling camel skins loaded on to live animal. Carrying water in skins bag on camel back is quite ancient and common even today in Indian deserts.

Human skins of enemies were used for seating, panelling city wall, covering quivers, drinking, etc. The Assyrian inscription such as one found in the British Museum mention the use of enemies skin to cover the city wall. This was discovered during the excavation of Ninerah. Skinning the enemy in those days even upto the British time in India was not an uncommon thing.

A leather box complete with surgeon's instruments of fashioned chicken bones dates to the 4000 B.C. A similar fashion in our ancient ayurvedic, unnani and other medical systems cannot be ruled out. It should not be forgotten that the burial of

dead body with some belongings in big earthern pot in India was not uncommon and leather articles should have found a place in some of these pots known as 'urns'. Even in very ancient time, man travelled vast distances taking with him his art and culture to blend with those of other countries.

In Vedic times, there was no prejudice against using receptacle made of hide for storing butter and ghee. Skiṇ utensils were in great demand in the ancient Aryan society. There were leather bags, vessels etc. for storing water, wine, honey, somabana, etc. In the time of *Ṛgveda*, leather *Māsaka* for water was well known. It is also mentioned as "*driti*" and finds use even today in northern India. Leather bag made from camel hide is used for transporting water in the desert regions of Rajasthan and Gujarat. The *Rāmāyaṇa* narrates the practice of watering the street using '*Masaka*' to reduce the dust nuisance.

Rajasthan is specially noted for manufacturing decorative leather bottles. Samples of wonderfully decorated and plain leather bottles are kept in the Central Leather Research Institute, Madras. *Kuppi* or *Kuppa* is a native word for leather bottle extensively used in the northern part of India for keeping oil and essence. In preparing these bottles, cut out paper designs or pattern painted in white were inserted beneath a transparent membrane (*Fig. 4*).

Huka bottle known for a long time is made using clay model. A clay model of the exact form is mounted with raw camel hide or sheep skin in wet condition; after it is completely dried, container becomes very sturdy and durable. These leather bottles are decorated by painting or with cut out paper patterns and stamped designs. The paper patterns are sandwiched between two membrane of raw skin. The exquisite floral designs, sometimes with gold and silver, are traceable to Persian influence.

There is another type of ancient water carrier (*thol sal*) made with bark tanned hide heavily greased which, in general, is used by the cultivators for irrigation in Southern India. *Kavalai thol* is a South Indian term for a bark tanned short hide hose attached to a huge metal bowl for drawing water from deep wells for irrigation. Leather bags were universally used in India for drawing water from wells. Leather buckets were are also used in villages for drawing water from the wells.

Parchment

Parchment, dry skin free from hair and flesh, has many uses from time immortal. It was used in very ancient time as string, though strap, tent, boat, container, shield and drum to produce sound came later and found uses in the various percussion instruments, as sheet for writing and in shadow show as puppets of living personalities (mythological and historical) and other (building, forest, chariot, lotus, arrow, club etc.). It has other present use as lamp shade, lamp dome, dividing panels etc.

It cannot be denied the use of parchments scrolls in India in writing since it was in use in the other ancient countries as early as 2000 B.C. Indeed the earliest known documents on parchment include an Egyptian scroll 2000 B.C. Recently discovered Dead Sea scrolls which included a 23 feet long leather scroll with the complete text of the book of Isaiah dated 100 B.C

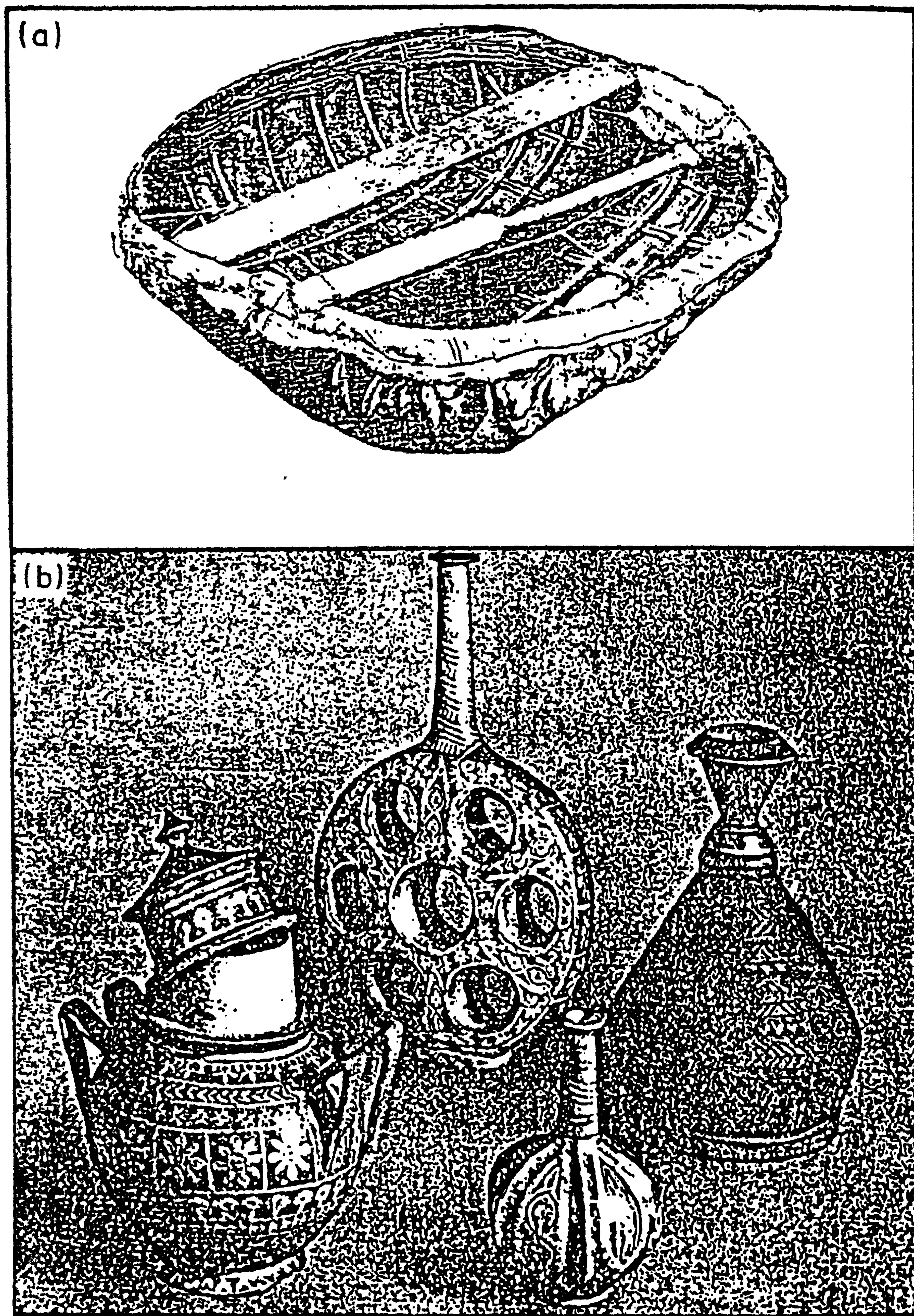


Fig.4. Ancient leathercraft for boat and container a) Leather Board b) Bottles moulded from camel hide made by natives of Bannu, N.W. Frontier Province of India

The Vedas as well as the epics *Rāmāyana* and *Mahābhārata* refer to various kinds of drums. The Saṃhitās and the Brāhmaṇas refer to the *Bhumi Duṇḍubi* (the big earthern drum). The *Deva Duṇḍubi* (celestial drum) is mentioned in the *Rāmāyaṇa*. Of the large military drum played with a stick, there were the *Ranadhaka* and the *Jaradhaka* with which the heroes of *Rāmāyaṇa* and the *Mahābhārata* are said to have inspired their legions with military ardour in the battle fields. The *Pañcamukha vadyam* itself is a royal sacred drum and is played in the Thyagaraja *Sannidhi* in the temple at Tiruvarur.

For thousands of years, news was sent by code sounds through parchment instrument for hundreds of miles by the peoples of different civilizations. Various announcements from palaces and worshipping places were also carried through these instruments which are finding a place even today in music concert, orchestra and visual presentations like drama, dance, film and television. The parchment has been expressing from time immemorial man's joys and sorrows, love and valour, fright and ferociousness, his watery natural calamities spiritual aspirations, patriotic feeling, psychic and physical needs in a tone understandable by people speaking various languages.

The drums are single and multifaceted. The '*Udukkai*' has single skinned face. But the right hand at the *Mṛdaṅgam* has three concentric rings of skin. In the *Pañcamukha Vādyam* in Tiruvarur, the faces have a circular ring of various types. The four hands along the periphery of the instrument have single skinned faces. The Mrdangam has to be periodically reskinned and the black paste renewed.

There is a rare instrument known ar *Pañcamugam* with five faces with deer and other skins fitted to a bronze egg shaped vessel. This type of instrument was known 2300 years ago. In the *Pañcamuga Vādyam*, the five heads are tuned to five different notes and with the two *kuḍa muzha* (pot drums) one on either side, the compass of the instrument will complete the *sapta svaras*.

The shape of the instrument differs. These were barrel shaped (*Mṛdangam*) hour glass shaped (*Udukkai*), cylindrical shaped (*Pambai*), conical (*Damaram*), pot shaped (*Kuda muzha*) etc. Drums are classified as martial drums, ceremonial drums, and message drums. The body of the *Mṛdaṅgam* is scooped out of single block of wood. Jack wood, red wood or the wood of the *Margosa* tree is used for making the body. The core of the coconut tree and palm tree are also used for the purpose. On the right of the *Mṛdaṅgam*, the inner most layer and the next ring are of cow skin and the outer most is of goat skin. First the three skins are stitched over the right head in a tight manner. The outer skin is sliced off the middle to make the inner ring and the inner most layer visible. The skin is stretched over the shell. Then the skin is dried in the sun. The skin of left head with the layers using cow and goat skins are also prepared in the same manner. After drying, both the heads are fixed tightly to the shell by putting circular rings made of twisted leather straps on both the drum heads.

The commonly accepted main classes of instruments are the strings, the wind and the percussion. These instruments were classified in the ancient Tamil Literature as *Tholkaruvi* (skin instrument eg. Mirudaṅgam), *Narambukaruvi* (animal gut instrument, eg. Yazh Nārangi), *Thulaikaruvi*

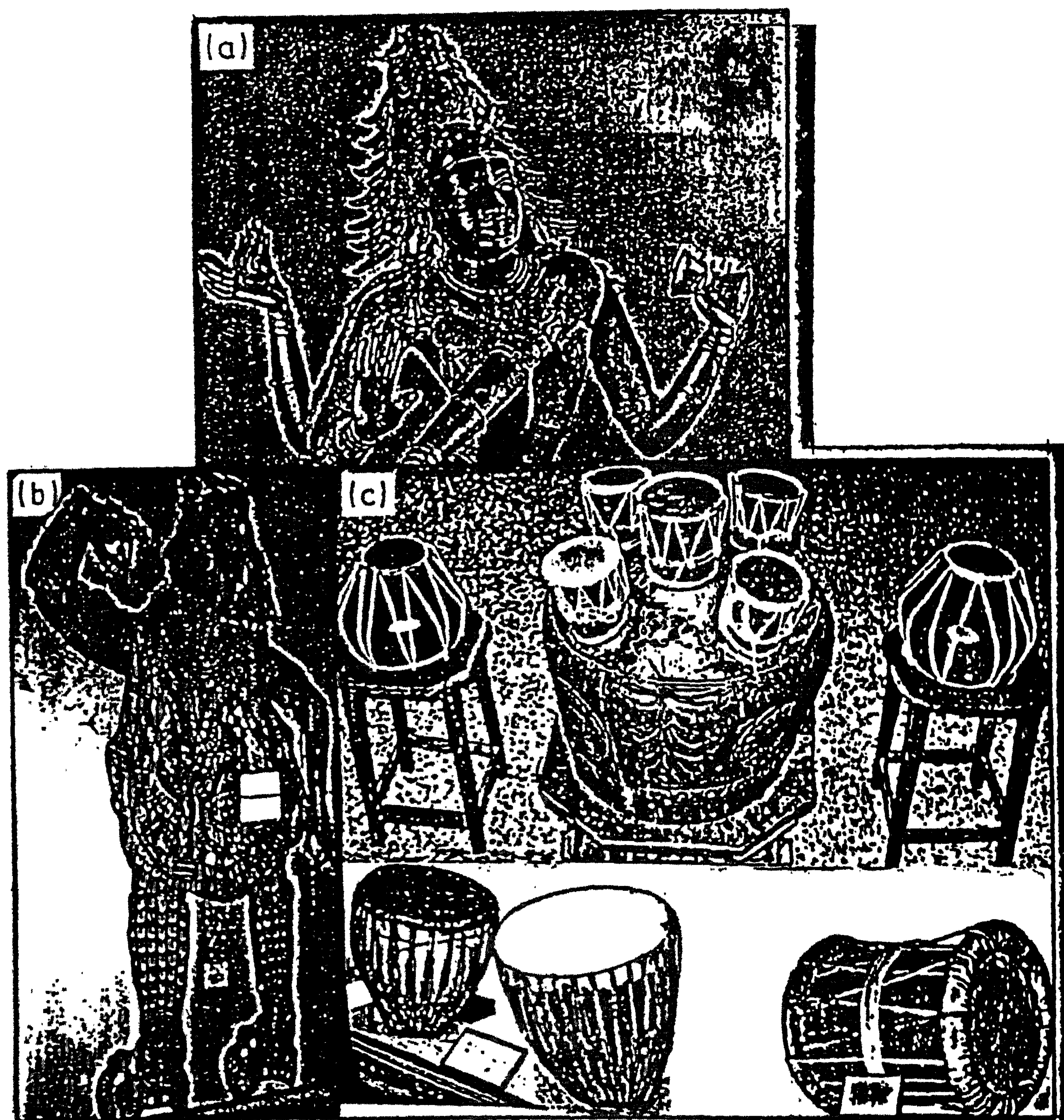


Fig.5. Ancient leathercraft using parchment a) Śiva's Dammar b) Shadow Puppet c) Percussion Musical Instruments.

(hole or wind instrument eg. Flute) and *Kañcakaruvi* (metal instrument eg. cymbals). The music is produced by striking, plucking, bowing, rubbing, and shaking. *Tholkaruvi* (Percussion instrument) has an earlier origin. Parchment musical instruments are found in all countries and are used by people belonging to all strata of society from prince to peasant. These instruments contribute rhythm and dynamism to whatever type of music they accompany. Rhythm comes naturally to man, since everything in creation moves towards it. Numerous varieties of drums, veenās, pipes, gongs and bells are shown in the ancient sculptures. The ancient 'Sāma Veda' among the four Vedas is devoted to the divine vocal music which was rendered

accompanied by suitable musical instrument. The parchment finds use not only in percussion instrument but also in certain type of string instruments. The gut, hair and horn of the animal origin are also used in stringed and wind instruments (*Fig. 5*).

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Concepts and Measures of Length, Weight and Time

A.K. BAG

There is no doubt that units of length, weight and time are basic parameters constructed by man. These parameters are considered as sources of all scientific thinking and lie at the root of natural knowledge. Their formulation and standardisation are based on observations and experiences made at different times and are involved without disturbing uniformity in nature or in measurements. The measure of a thing becomes standardised as a unit by general consent by its being compared with another of the same species. The measures of units of these parameters vary from one culture to another. The strength or the uniqueness is discernible when there is acceptance and influence in other cultures.

In India the units (*māna* or *parimāna*) are of two types, *Laukika* (worldly) and *Lokattara* (para-worldly). The *Laukika* deals with the process of measurement. The *Lokattara* type has theoretical connections with *Laukika* type and deals with length, and weight from smallest unit (atom) to last of the world space, and time from unit to infinite time. The Jain canons give another group, *bhāvamāna* (idea) under *Lokattara* type which deals with knowledge, perceptions, view points and numbers. Original sources have been collected and analysis of both these facets have been made in this paper, ofcourse in a limited manner, in order to find the religio-philosophical and social linkages from a variety of applications.

Length

The linear units originated mostly from the body measures and were used for the measures of distance or area (*kṣetra* or *varga*), or volume of solid figures (*ghana*). The idea of *varga-* and *ghana- māna* are sometimes mentioned or understood from the contexts. The linear units were also connected with the circumferences of the earth from which modern equivalents of different units have been computed.

Primary Sources:

The Indus Valley has recorded four measuring rods with markings viz. one broken scale made of shell (M.614) from Mohenjo-daro, one broken bronze rod

from Harappa, one graduated scale from Kalibangan, and an ivory rod from Lothal. The broken Mohenjo-daro scale shows nine consecutive uniform parallel lines having a circle on one line and a deep dot on sixth line. The distance of these five intervals is equal to 1.32 inches. Mackay (1931) believed this distance as a part of the whole which is ten times bigger i.e. 13.2 inches giving a decimal connection and having linkages with that of the ancient Egypt and Elam. Berriman (1953) described the distance between the circle and the dot as Indus scale, since 25 Indus inches are exactly equal to 33 inches ($25 \times 1.32 = 33$).

The *Ṛgveda* and other Vedas used the words, *puruṣa, aratni, pada, aṅgula, parva, muṣṭi*, etc. for linear measures (Macdonell and Keith). The *Puruṣa* is defined in the Vedic literature as the measure of a man with outstretched arms. The *Śulba Sūtras* of Baudhāyana (BSI.1.3) and Āpastamba (ASl.6.5,15.4) used *rajju* or rope with marks and knots and give the units as follows:

One *puruṣa* (measure of man with out-stretched arms) = one *vyāma* = 5 *aratnis* = 120 *aṅgulas (or aṅg)*.

One *vyāyāma* (measure of stretched arms) = 4 *aratnis* = 96 *aṅg.*

One *śamyā* = one bāhu = 36 *aṅg.*

One *jānu* = 32 *aṅg*;

One *aratni* = 2 *prādeśas* = 24 *aṅg.*

One *prādeśa* = one *prakrama* = one *pada* = 12 *aṅg.*

One big *pada* = 15 aṅg; one small *pada* = 10 *aṅg.*

One *aṅgula* = 12 *aṇus* = 34 *tilas*

These are body measures. There are three other measures, *akṣa* (axle), *iṣā* (pole) and *yuga* (yoke), often referred to by the *Ṛgveda* and other Vedas in connection to Chariot (*ratha*) measures.

Baudhāyana (BSl. 1-3) gives that one *akṣa* = 104 *aṅg*; one *iṣā* = 188 *aṅg*; one *yuga* = 86 *aṅg.* These units have also been used in the Kātyāyana and Mānava Śulbasūtras.

Buddhist and Jain sources gave emphasis to both practical and theoretical aspects.The *Lalitavistāra* (Datta and Singh, 1, p.187) has mentioned as follows:

One *yojana* = 4 *krośa*; 1 *krośa* = 1000 *dhaṇus.*

One *dhaṇu* = 4 *hastas*; 1 *hasta* = 2 *vitastis*

One *vitasti* = 12 *aṅguli parvas.*

So 1 *yojana* = 4000 *dhaṇus*;

1 *dhaṇu* = 96 *aṅg.* and 1 *hasta* = 24 *aṅg.*

As regards smaller units from *angula*, there are 10 units, each is one-seventh of the former. These are *aṅgula, yava, sarṣapa, likṣā-raja, go-raja, eḍaka-raja, śaśa-raja, vātāyana- raja, truṭi, reṇu* and *paramāṇu*. Obviously 1 *paramāṇu* = 7^{-10} *aṅgula.*

The Kauṭilya *Arthaśāstra* (Shyamasastri (ed) 1956, p.117) gives as follows:

One *yojana* = 4 *goruta* (distance to reach the sound of a cow),

1 *goruta* = 1000 *daṇḍas* (or *dhaṇus*), since *dhaṇus* and *daṇḍas* are synonymous.

1 *daṇḍa* = 4 *aratnis*, 1 *aratni* = 2 *vitasti*, 1 *vitasti* = 12 *aṅgulas*

So 1 *yojana* = 4000 *daṇḍas*; 1 *daṇḍa* = 96 *aṅg*. and 1 *aratni* = 24 *aṅg*

Daṇḍa of 96 *aṅg* is equal to the height of the normal man. It was used also for measuring areas. *Daṇḍa* and *puruṣa* become synonymous during Kauṭilya's time (Agrawala, 1953, p.256).

Kauṭilya also gives four smaller units of *angula*. These are *yuka*, *likṣā*, *rathadhuli* and *paramāṇu*, the latter is lesser by eight part than the former.

Hence one aṅgula = 8^4 *paramāṇu*, and 1 *paramāṇu* = 8^{-4} *ang*.

The *Bṛhat Saṃhitā* (ch. 58, vs.1-2) of Varāhamihira (505 A.D.) gives as under:

One *yojana* = 4 *krośas*, 1 *krośa* = 25 *nalvas*;

1 *nalva* = 40 *dhaṇus*; 1 *dhanu* = 4 *hastas*;

1 *hasta* = 24 *aṅg*. So 1 *yojana* = 4000 *dhaṇus*;

1 *dhaṇu* = 96 *aṅg*.

The smaller units from *aṅgula* as given by Varāhamihira are *yava*, *yuka*, *likṣā*, *vālāgra*, *ratha raja*, *paramāṇu*, each 8th part smaller than the former.

Hence 1 *aṅg*. = 8^6 *paramāṇus* or 1 *paramāṇu* = 8^{-6} *aṅg*.

Varāhamihira has also mentioned (ch. 68, vs.105). "The height of a tall, normal and short man is 108 aṅgulas, 96 aṅgulas and 84 aṅgulas by his own measure". The height of the normal man during Varāhamihira's time was 96 *aṅgulas*, and height of the normal man with out-stretched arms will obviously become equal to height of the man and one aratni, i.e. 96 *aṅgulas* + 24 *aṅgulas* = 120 *aṅgulas*, which corroborates with Vedic measure. He further pointed out (*Bṛhatsaṃhitā*, Shamasastry, 1910, p.109), "An army of the lowest standard can march one yojana, that of middle standard one and half yojana, and that of the best standard two yojanas". So middle standard army can march = $1^1/_2$ yojanas = $1^1/_2 \times 4000$ *daṇḍas* (or *dhaṇu*) = 6000 *daṇḍas*.

The Jain work, *Anuogadvāra Sūtra* (Sūtra 131) gives as follows:

One *yojana* = 4 *gavyayuties*; 1 *gavyayuta*

= 2000 *dhaṇusyas*; 1 *dhaṇusya* = 2 *kukṣis*

1 *kukṣi* = 2 *aratnis*; 1 *aratni* = 2 *vitastis*,

1 *vitasti* = 2 *padas*; 1 *pada* = 6 *aṅg*.

This shows 1 *yojana* = 8000 *dhaṇusyas*

1 *dhaṇusya* = 96 *aṅg*. and 1.*aratni* = 24 *aṅg*.

Āryabhaṭa 1 (499 A.D.) used the word *nṛ* as synonymous to *daṇḍa* or *dhaṇus* which is equal to the height of the average man, i.e. 1 *daṇḍa* = 1 *nṛ* = 4 *hastas* = 96 *ang*, since 1 *hasta* = 24 *aṅgs*. But he has used one *yojana* = 8000 *nṛ*.

The *Brāhmasphuṭasiddhanta* of Brahmagupta (i.37), *Sūryasiddhānta*, *Siddhantaśekhara* of Śrīpati (ii 94) and *Siddhāntaśiromani* of Bhāskara II (SSI i.43) have the value of the circumference of the earth as 5000 *yojanas*. All astronomers from Āryabhaṭa I to Bhāskara II (c 1150 A.D.) have used 1 *yojana* =

8000 *daṇḍas* (*Āryabhaṭīya*,, iii.7; *Gaṇitasāra Sangraha* of Mahāvīra, i.29-31 1/2, *Vaṭeśvarasiddhānta*, i.7-13).

Mahāvīra has used smaller units of *aṅgula* as 1 *aṅg* = 8^8 *paramāṇu*, *aṇu* is added between *paramāṇu* and *trasareṇu*.

The measure of *aratni* i.e. 1 *aratni* = 24 *aṅg* has been kept as same through out.

Thus we find the units of *yojana* i.e. 1 *yojana* = 4000 *daṇḍas* from earliest time to the time of Varāhamihira, and 1 *yojana* = 8000 *daṇḍas* were introduced thereafter, the reason for switching over to this bigger value is not clear. Thus double value of *yojanas* or *krośas* are still prevelent in Bengal, Bihar and other States.

Hiuen Tsang (c.650 A.D) in his historical account on India, has recorded that there were two *krośas* in India, an old one of 1000 *daṇḍas* and new one of 2000 *daṇḍas* reckoning in his time. Since 1 *yojana* = 4 *krośas*. This statement of Hiuen Tsang also corroborates that 1 *yojana* = 4000 *daṇḍas* (old measure) and 8000 *daṇḍas* (new measure) and the historical situation prevalent in his time. Āl- Bīrūnī (c.1030 A.O.) studied astronomical data of the Indians and related *yojana* with *farsakh* and *yard* without any definition (Mainkar, 1975). Vogt (1903), Fleet (1906, 1912), Shamasastry (1913) tried to establish correlation with chinese *li* and units of other countries which have not also of much correlation.

Yojana, Daṇḍa, Aratni and Aṅgula (Values in inches):

There are many conjectures about the modern equivalent value of the units of *Yojana, Daṇḍa, Aratni* and *Aṅgula*. These may be summarised as follows:

Dongre (1994) on the basis of Ṛgvedic Purusa Sukta[1] believes that one *Puruṣa sphere*, and the Earth's circumference, thus: Purusa sphere = 1000 × 2000 × 2000 ang. = 4×10^9 *aṅg*.

Earth's circumference, as per this *sukta* remains one aṅgula below that of the Purusa sphere of radius of 1 aratni. Hence Earth's circumference = $24/25 \times 4 \times 10^9$ = $96 \times 4 \times 10^7$ *aṅg* = 4×10^7 *daṇḍas*. The astronomical texts give the circumference of the Earth mostly as 5000 *yojanas*

= 5000 × 8000 *daṇḍas*

= 4×10^7 *daṇḍas*.

The lesser value of 4000 *daṇḍas* for yojanas was possibly not found compatible by the astronomers of 4-5th century. Of course there may be other reasons.

The present value of the Equatorial circumference of the Earth = 24900 miles (Encyclopadia) = 4×10^7 metres.

From this Dongre concludes that 1 daṇḍa = 1 metre

This gives 1 aṅgula = 100/96 = 1.04167 cm.

We find use of *aṅgula*, *parva* and *muṣṭi aṅgula* in Vedic and Post- vedic India.

Dongre believes that *muṣṭi* (= 4 *ang* = 4 × 100/96 = 4.16cm) and *parva* (= 3 *aṅg* = 3 × 100/96 = 3.125 cm) were of great significance.

For, cube of one *muṣṭi ang* and *parva aṅg* changed into sphere, the radius becomes: (1 muṣṭi *ang*)^3 = (4.16 cms)^3 = $4/3\pi r_1^3$.

Thus r_1 = 2.58 cms. = 1.016 inches

Again, (1 parva *aṅg*)^3 = (3.125 cm)^3 = $4/3r\,\pi\, r_2^3$, r_2 = 0.76 inches.

The *muṣṭi aṅg* unit was much bigger and has a connection with Indus scale for $4/3\pi$ (1.016 inches)^3 = (1.32 inches)^3. Since value of the Indus scale = 1.32 inches.

The *parva aṅg* unit is possibly used from Vedic period onwards. More work will be of interest to know whether the *parva aṅg* and *muṣṭi aṅg* units are responsibile for two values of *yojana* or *krośa* in later period. However, *parva aṅg* is possibly followed more or less uniformly in linear measure as follows:-

1 *hasta* = 24 *aṅg* = 24 × 0.76 inches

= 18.24 inches = 18 inches (approximately),

1 *aṅgula* = 0.76 inches

= 3/4 inches (approximately)

However Ayurvedic Pharmacopoeia Committee (*Ayurvedic Formulary of India*, Pt.1) recommended the same *parva* values for *hasta* and *aṅgula* as given above though the basis for selecting the values are not made clear.

Weight

The units are usually based on natural elements or phenomenon. What about weight? These are mostly represented by the weight of an object like, a seed (*māṣa* or *guñja*) or a piece of metal. If the objects are lost, the very basis of a system is lost. The fact was not possibly unknown to the ancient Indians. There is enough hint in the *Arthaśāstra* that the weight of *māṣa* (Phraseolus Radiatus) was standardized with volume of one *aṅgula* of water. Whether this *māṣa* of ancient India has any connection with *mass* of CGS system is a matter of great interest and still to be investigated.

Primary sources

The archaeological sites of Harappa, Mohenjodaro, Chanhuḍaro and Lothal bear testimony that weighing balances were known. It consisted of a metallic beam (copper or bronze) with two suspending pans from its two ends (Mackey, 1938, pp.976-77; Mackey, 1976, pp.178, 293; Vat, 1940, pt.CXVII and CXVIII; Marshall 1931). Berriman (1953, pp.33-35) has analysed 288 specimens of small cubes available from Mohenjodaro and Harappa and drawn a frequency chart as parts of 1 *unicia* = 27.2 gms. These weights are 1.7, 3.4, 6.8, 13.6, 27.2, 54.4, 136 (gms) etc. The beams of weighing balance were uniform, sometimes thicker in the middle and tapering at the end. The beam had no fulcrum hole in the centre. A string was perhaps tied at the middle for holding it during weighing. The pans had two or three holes for suspension. Pans with two holes were possibly used for bulky materials which one could hold by touching it, whereas pans with three holes were used for

weighing grains and commodities. The Mohenjodaro had two types, one similar to Harappan types and the other is of smaller type (scale pans of copper or bronze). The Chanhudaro and Lothal sites have also small pan and beam types. These smaller types were perhaps used for weighing gold dust and other precious metals, for these could weigh micro-weights (Sharma and Bhardwaj, 1989).

The Ancient Indian names for balance was *tulā*. The *Vājasaneyī Saṃhitā* (30.17), *Śatapatha Brāhmaṇa* (2.2.7.33), *Vaśiṣṭha Dharmasūtra* (19.18.23) and *Aṣṭādhyāyī* of *Pāṇini* (4.4.51) bear testimony that equal arm balance of different sizes were used (Agrawal, 1953, p.251). The Vedic literature have used measuring units viz. *kṛṣṇala, aṇḍaka, māṣa, śana, suvarṇa* (*TS.* 2.3.2.1; *Mait S.* 2.2.2; *Kat. Sr.* 11.4; *T Br.* 1.3.6.7 etc.). *Māṣa* is a standard kind of seed (*Phraseolus Radiatus*). The weight can vary in different atmospheric conditions. Then how is it that such seed have been used. Dongre believes[2] that it is possibly standardized to be equal to volume one *angula* of water i.e. 1 *māṣa* = $(1.04167 \text{ cm})^3$ = 1.13 gms for it fits very well with other measures. The vedic units are as follows:

1 *māṣa* = 4 *aṇḍakas* = 5 *kṛṣṇalas* = 1.13 gms ;

4 *māṣas* = 1 *śana* = 4.52 gms; 4 *śanas* = 1 *suvarṇa* or

1 *karṣa* = 18.08 gms;

4 *suvarṇas* = 1 *niska* = 72.32 gms.

Obviously one *andaka* = 1/4 *māṣa* = 0.28 gms; one *kṛṣṇala* =

1/5 *māṣa* = 0.226 gms.

The *kṛṣṇala* (*Guñja, Ratikā*), the black-and-red berry of the shrub (*Abrus Precatorius*) was used as a natural measure (Seal, pp.80- 85).

The *Arthaśāstra* of Kauṭilya gives a detail description as to the varieties of balances, measures to check the inaccuracy of balances, methods of state control of weights under the superintendent of weights and measures (*Pantādhyakṣa*). The coins were also struck in gold, silver and copper in accurate weights besides commercial activities of ornaments and commodities. Strict steps were taken to avoid debasement of currency metals. The dust currency of gold and silver (*cūrṇi* or *cūrṇa*) were also in vouge. The accurate weights were considered important for all these activities.

Kauṭilya's *Arthaśāstra* gives a series of weight measures (Shamasastry, Eng. tr. 1956, pp.113-132) as follows:

Gold weight: 5 *guñjās* (*Abrus Precatorius*) = 1 *suvarṇa māṣa* = 1.13 gms;

16 *suvarṇa māṣas* = 1 *suvarṇa pala* or *karsa* = 18.08 gms.

Suvarṇa series as given by *Arthaśāstra* are:

Ardhamāṣa (=0.56 gms), 1 *māṣa* (=1.13 gms), 2 *māṣas* (=2.26 gms),

4 *māṣas* (=4.52 gms), 8 *māṣas* (=9.04 gms), 16 *māṣas* (=1 *suvarṇa pala* = 1 *karṣa* = 1 *bisto* = 1 *akṣa*, = 18.08 gms), 2 *suvarṇa palas* (= 36.16 gms) and so on.

Kauṭilya states, "The increase in density (*gaurava vṛddhi*) is increase in matter or price (*satva*) for all metals of equal volumes"[3]. The densities of gold, silver, copper and iron are 19.3, 10.5, 8.96 and 7.86 respectively, obviously for equal

volumes of these metals, silver or copper is 2 times of gold weight and iron is 2.5 times or 3 times of gold weight, i.e.

1 ***silver pala*** = 1 copper pala = 2 suvarṇa pala
= 2 × 16 = 32 *māṣas* = 32 × 1.13 gms
= 36.16 gms. = 36.00 gms (approx.)

1 ***Iron pala*** = 2.5 suvarṇa pala
= 2.5 × 16 *māṣa* = 40 *māṣas*
= 40 × 1.13 gms = 4520 gms
or = 3 suvarṇa pala
= 3 × 1.6 *māṣas*
= 48 *māṣas* = 48 × 1.13 gms
= 54.24 gms

Silver units of Kauṭilya are:

88 mastered seeds = 1 silver *māṣa*;
16 silver *māṣas* or 20 *śaiba* seeds = 1 *dhāraṇa*,
10 *dhāraṇas* = 1 silver pala.
1 silver pala = 36.00 gms, 1 *dhārana* = 3.600 gms.
1 silver *māṣa* = 0.225 gms, 1 *śaiba* seed = 0.18 gms,

Silver Series: 1 silver *māṣa* (= 0.225 gms), 2 silver māṣa (= 0.45 gms), 4 silver *māṣa* (= 0.90 gms), 16 silver *māṣas* (= 3.60 gms = 1 *dhāraṇa*), 2 *dhāraṇa* (7.2 gms), 10 *dhāraṇa* (36.00 = a silver pala) and so on.

Similarly, Iron pala = 40 *māṣas* = 45.20 gms, or = 48 *māṣas* = 54.24 gms.

Series of Iron weights (*lauhapalas*):
1/32, 1/16, 1/8, 1/4, 1/3, 1/2, 1, 2, 3...100 lauhapalas.

This results in:
1st series: 1.41 gms, 2.82 gms, 5.64 gms, 11.28 gms, 15.7 gms.
22.60 gms, 45.20 gms, 90.40 gms and so on (when 1 pala = 40 māṣas).

2nd series: 1.69 gms, 3.39 gms, 7.72 gms, 15.44 gms, 18.04 gms, 27.12 gms, 54.24 gms, 108.48 gms. and so on. (when 1 pala = 48 māṣas).

The second series is comparable with weights of Mohenjo-daro given by Berriman.

There are *bhājanī* or division measures. The *vyāvahārikī Bhājanī* and *Antaḥpura Bhājanī* systems of *Arthaśāstra* bear resemblances to Greek, Persian and Roman systems when one *masa* = 18 Troy grain.

The *Kātyāyanī* or *Viṃśatikā* system used: 25 *kṛṣṇala* = 1 *pada* = 2.825 gms, 4 *padas* = 1 *śatamāna* or 1 *paṇitala* = 11.30 gms. This gives *śatamāna* = 100 krsnalas.

Series for weights of medicine:

The *Caraka Saṃhitā* (Kalpasthāna, 12.87-97) gives measures which are used for preparation of medicine. These are:

6 *dhansis* = 1 *mārici* = .00074 gms;

6 *māricis* = 1 *sarṣapa* = .00444 gms.,

8 *saraṣapa* = 1 *taṇḍula* = .035 gms.

2 *taṇḍulas* = 1 *dhānyamāṣa* = .07 gms,

4 *dhānyamāṣas* = 1 *aṇḍikā* = 0.28 gms.,

4 *aṇḍikās* = 1 *māṣa* = 1.13 gms;

3 *māṣas* = 1 *śāṇa* = 3.39 gms;

2 *śānas* = 1 *danksana* = 6.78 gms.

2 *dankṣaṇas* = 1 *karṣa* = 13.56 gms.

So 1 *śāṇa* = 1/4 *karṣa*.

The *Suśruta saṃhitā* has used the similar units.

The word *bhāra* is referred to in Pāṇini Sūtra (VI. 2.38) in connection with *mahābhāra*. It is a *samjña* word with a definite meaning. *Amarakośa* (II. 9.87) gives 1 *bhāra* = 8000 *karṣas* = 145 kg. Kauṭilya (II.19) records 1 *bhāra* = 20 tūlās = 20 × 100 *palas* = 2000 *palas*, 1 *tūlā* = 7.2 kg. *Bhāra* appears to be headload and *Mahābhāra* may be a cart load.

Māhāvira (850 A.D.) in his *Gaṇitasāra Saṃgraha* (i. 39-45) gives as under:

Gold weight :

4 *andakas* = 1 *guñja* = 0.226 gms

5 *gunjas*= 1 *paṇa* = 1.13 gms.

8 *paṇas* = 1 (gold) *dhāraṇa* = 9.04 gms.

2 *dhāraṇas* = 1 *karṣa* or *suvarṇa pala* = 18.08 gms

Silver weight :

2 *dhānyas* = 1 *guñja* = 0.113 gms.

2 *guñjas* = 1 *māṣa* = 0.228 gms

16 *māṣas* = 1 (silver) *dhāraṇa* = 3.64 gms.

$2^1/_4$ dhāraṇas = 1 *karṣapurāṇa* = 1 silver *māṣa* = 8.04 gms.

4 *karṣa pūrāṇa* = 1 silver *pala* = 32.82 gms. This is less than weight of Kauṭilya's time.

***Iron weights** are given as:*

Pāda, *kalā*, *yava*, *aṃśa*, *bhāga*, *draksuna*, *dinar* and *sater* which are doubtful as to their correctness. It also gives 1 *bhāra* = 10 *tūlās*, 1 *tula* = 200 *palas*, thereby, *bhāra* = 2000 palas, with difference.

Śrīdhara's *Pāṭīgaṇita* (vs. iv) records gold measures, the same as that of Kauṭilya's *Arthaśāstra* i.e.

5 *guñjas* (Alrus seeds) = 1 *suvarṇa māṣa*

16 *suvarṇa māṣas* = 1 *karṣa* (of gold).

Bhāskara II records Turkish and units introduced by Badshah Alamgir on weight measures as follows:

Turkish units : 96 *yava* = 1 *gadyanaka*

72 *tanks* = 1 *ser*

40 *sers* = 1 *man* (maund)

Badshāh Ālamgīr units : 192 *dhātakas* or *tolās* = 1 *ser*

5 *ser* = 1 *dhātikā*, 8 *dhātikās* = 1 *man* (maund)

This shows that new units of weight measures have started being introduced during the time of Bhāskara II (1150 AD)and Bādshah Ālamgīr.

Time

The ancients realized on the basis of a clearly agreed experience that there is a unique serial order of events (i.e. one dimensional). This was the foundation of a trustworthy system for the dating of events by the use of calendars, dynasties the primitive sundial and water clock. This notion of time is somewhat different from what it is to theoretical Physics or it is to thermodynamics or to evolutionary sciences such as biology. The early notion of time is mostly connected with the natural phenomenon of day and night. The concept of past, present and future has added an additional difficulty of another dimension into it. I am always in my 'present' and can experience no other parts of time which is 'past' or 'future'. Only the 'present' is real and has the character of a knife-edge which separates non-existant past from a non-existant future. We will first compile sources on the natural phenomenon of time and then analyse its attribute and impact from different perspectives.

Primary Sources : The *Ṛgveda* (2.28.8) mentions three ordinary divisions of time, namely, present, past and future. Time is identified with the Sun and the Viṣṇu and is also divided into divisions like *muhūrtas*, days, half months, months, seasons, solstices, year, *yuga*, *kalpa*, *mahākalpa* and so on. The whole forms a circle which like a wheel is constantly moving. The word *muhūrta* appears in the *Ṛgveda*. The *muhūrta* as part of a day first appears in the Brāhmaṇas. The *Taittirīya Brāhmaṇa* (3.10.1. 1-3, 10..9.7) gives the name of each *muhūrta*. The *Śatapatha Brāhmaṇa* (12.3.2.5) gives further subdivision of year into *muhūrtas* as follows: 1 year = 10800 *muhūrtas*;

1 *muhūrta* = 15 *kṣipras*;1 *kṣipra* = 15 *etarhis*;1 *etarhi* = 15 *idānis* 1 *idānis* = 15 *prāṇas* (breathings) etc.

The *Vedāṅga Jyotiṣa* gives the smaller units of day the *muhūrta*, *vaidika*, *kāla*, *ādaka*, *kuḍava* and *pala*. The time of these units was measured by water clocks. The units are: 1 day = 30 *muhūrtas*, 1 *muhūrta* = 2 *nādis*, 1 *nāḍika* = 10 *kalās*.

Sphujidhvaja in his *Yavanajātaka* (3rd century A.D.) has taken 1 *nāḍikā* = 10 *kalās* to avoid fraction or followed Suśruta (Shukla, 1989, p.213).

The Jainas and Buddhists used large numbers for measurments of space and time. The *Lalitavistāra* usèd as big as 10^{53}. The Jaina used the number 10^{140}

(*asaṃkhya*), measurement of time as *pūrvī* where one *pūrvī* = 756 x 10^{11} years and one *śirṣa-prahelikā* = (84 x 10^5)^{28} *pūrvīs*. The introductions of such large numbers led to the conception of infinity which is not very precise from practical point of view.

The *Atharva Jyotiṣa* gives the subdivision of day i.e. *ahorātra* (day and night together) as *muhūrta, truṭi, kalā, lava,* former being 30 times of the latter.

Kauṭilya gives (Shamasastry, 1956, p.118-119), 1 day (day & night) = 30 *muhūrtas*, 1 *muhūrta* = 2 *nālikā*, 1 *nalikā* = 40 *kalās*, 1 *kalā* = 30 *kāṣṭhās*, 1 *kāṣṭhā* = 5 *nimesa*, 1 *nimesa* = 2 *lavas* and 1 *lava* = 2 *truṭis*. From days and nights, Kauṭilya goes upto month, *ṛbu* (season), *ayana* (solstices), *samvatsara* (year), and *yuga*. Udayana's *Kiranāvalī* and *Śrīdhara's Nyayakandalī* give: 1 day (24 hours) = 30 *muhūrtas*, 1 *muhūrta* = 30 *kāṣṭhās*, 1 *kaṣṭhā* = 18 *nimeṣas*, 1 *nimeṣa* = 2 *lavas*, 1 *lava* = 2 *kṣanas*. This makes 1 *kṣana* = 2/45 seconds, if 1 day is taken as 24 hours, which was possibly determined from diurnal rotation of the earth.

Āryabhaṭa I (b.496 A.D.) gives:

1 year = 12 months, 1 month = 30 days, 1 day = 60 *nāḍis* or *nādikās*), 1 *nāḍi* = 60 *viṇāḍis*, 1 sidereal *viṇāḍi* = 60 long syllables or 6 *prāṇas* (respirations) (*Āryabhaṭīya* Tr. Shukla, 1976, p.86). The *Sūryasiddhānta* (i.11) gives the same table.

In the *Smṛtis* as also in the *Sūryasiddhānta*, the time division are 1 *kalpa* = 14 *manus*, 1 *manu* = 71 *yugas* and 1 *yuga* = 4320000 years. A small period preceding and following each Manu called twilight has also been conceived to make one *kalpa* equivalent to 1000 *yugas*. A portion is earmarked for the creation of the world, so that when world-order starts, plants occupy the same place. Āryabhaṭa I (p. 496 A.D.) does not believe in the theory of creation and annihilation of the world. For him, the time is a continous process, without begining and end (*anādi* and *ananta*). The begining of *yuga* and *kalpa*, according to him, having nothing to do with terrestrial occurance, they are accordingly based on astronomical phenomena. Āryabhaṭa I rejected the highly artificial time division with the following : 1 *kalpa* = 14 *manus*; 1 *manu* = 72 *yugas*; 1 *yuga* = 4320000 years. One *yuga* was again divided into 4 small *yugas* viz. *kṛta* (17,28000 years). *Tretā* (12,96000 years) *Dvāpara* (8,64000 years), and *Kali* (4,32000 years). So the *Sūryasiddhānta* and *Āryabhata* I believe that the current Kaliyuga began on Friday 18, 3102 B.C.

The *Gaṇitasārasaṃgraha* (i. 32-35) of Mahāvīra gives a time division of year as *ayana, ṛtu, māsa, pakṣa, dina,* the same value as others. Further down he gives:

1 *dina* = 30 *muhūrtas*; 1 *muhūrta* = 2 *ghaṭis*; 1 *ghaṭī* = 38 *lavas*; 1 *lava* = 7 *stokas*, 1 *stoka* = 7 *ucchvāsas*; 1 *ucchvāsa* = *saṅkhyāta avali*; 1 *avali* = *asaṃkhyāta samaya*.

The *Vaṭesvarasiddhānta* (i. 8-9) gives same for *kalpa, yuga,* year, month and day. From day to *truṭi*, the months are as follows: 1 day = 60 *ghatikās* (24 hours); 1 *ghaṭikā* = 60 *palas* (24 minutes); 1 sidered *pala* (*vinadi, vighaṭikā* or *casaka*) = 6 *asus*, 1 *asu* (respiration) = 2½ *kāṣṭhās* = 4 seconds; 1 *kāṣṭhā* = 4 long syllabus; 1 long syllabus = 4½ *nimeṣas* (twinkling of an eye);

1 *nimesa* = 100 *lavas*; 1 lava = 100 *truṭis*. Similar divisions are also found in the *Brāhmasphuṭasiddhānta* (i. 5-6) of Brahmagupta, *Siddhāntaśekhara* of Śrīpati (i.11-15; i.3, see also Makkibhaṭṭa's commentary).

Bhāskara II (1150 A.D.) notes, 1 day (24 hours) = 30 *kṣaṇas*; 1 *kṣaṇa* = 2 *ghaṭikās* (48 minutes); 1 *ghaṭikā* = 30 *kalās* (24 minutes); 1 *kalā* = 30 *kāṣṭhās* (48 seconds); 1 *kāṣṭhā* = 18 *nimeṣas*, 1 *nimesa* = 30 *tatparas*, 1 *tatpara* = 100 *trutis*, 1 *truti* (lotus pricking time) = 1/33,750 of a second. Bhāskara II while computing the instantaneous motion of planets compared its successive positions and considered its motion as constant during the interval which cannot be greater than a *truṭi* of time, though it may be infinitely less.

Concluding Remarks

The concepts of length, weight and time, in their origin and ramifications have been an integral part of the Indian religio- philosophical and social system. These concepts attempted to explain the limited material world on one hand and tried to speculate their relationship with unlimited world on the other. For linear measure they have developed a length - measured from *aṅgula* to *yojana* for practical purposes, but conceived as small a unit as *aṇu* and gave the diameter of earth as big as 10^5 *yojanas*, associating them with number and extending it from beginning to infinity (*ādi* and *ananta*), which is one dimensional. Area and volume were obtained by length and breadth; length, breadth and height respectively by the same scale. Whether the Indian had clear picture of dimension upto 12th century is not known. As regards weight, the words, *gaurava* (density), *gurūtva* (gravity or heaviness), *bhāra* (weight) were used. According to *Nyāya Vaiśesika*, gravity is one of the attribute of matter and regarded it not as a force but as a causal factor associated with act of falling or rising. There was possibly no correlation with gravity and mass. But to equate *māṣa* with the volumes of one aṅgula of water is indeed a unique step. The word *bhāra* for weight was used by later scholars in the same sense as before. The number is also an attribute of matter and there are expressions from insignificant weight to a very large weight. The knowledge, view points, perceptions and numbers give it also some significance but not over practical uses. Time is divided into day and its sub-divisions months, seasons, solstices, year, *yuga*, *kalpa* and *mahākalpa*.

Though the division is astronomical and cyclic in nature, the concept of smaller *kali yuga* (432000 years) and its beginning in 3102 B.C. leaves a terrestrial association in mind. The doctrine of transmigration of soul in Indian heritage i.e. life after death and effect of good and evil deeds in future life created an endless time, though the basic problem revolves round *ātman*, *brahman*, *nirvāṇa* (soul becomes free from the world), and the literature is full of discussion on *puruṣa*, *prakṛti*, *guṇas*, *mind* reflection of mind (*māyā*), immortality of mind and confusing conceptions of phenomenal world and various related matter. This is unlike Judaism, Christianity and Islam which had a limited nature of universe commencing from a period of 4000 years B.C.

The idea of past, present and future gives us also an idea of linear time which is as if something is moving forward from the moment of creation. The Eurocentric imagination has introduced modernism, progress in place of future and has assimilated what is best of other cultures, first as a philosophical method then as a political method (revolution) and as an artistic method (*avant garde*). Modernity

never looks, towards individual, rather looks towards human race through progress. There are also words like *muhūrta* (constant),*kṣaṇa* (moment) as ultimate unit of time. The followers of yoga school of Patañjali imagine that there is an uninterrupted flow of time of these moments. Ilya Prigogine, the Noble Laureate and the eminent theoretical Physicist has explained the idea of instant with a beautiful example with reference to Indian Culture. He says, be it a dancing Śiva or a miniature in temple - in which there appears very clearly the search for a junction between stillness and motion, time arrested and time passing. The instant is just like a window to the other side of time-eternity. The other world can be glimpsed in the flash of its existence. This reconciles among past, present and eternity. Indians had concepts of time but did not try to reconcile them in life with terrestrial activities, possibly because of religio-philosophical orientation in the society.

Notes

1. *The first ṛca (stanza) of Puruṣa - sukta (vs. 1) of the Ṛgveda, arranged in prose form is as follows:*

   Sahasra śirṣā sahasrākṣah sahasrapat (aṅgulaḥ) saḥ purusah vis vatah bhumiṃ vṛtvā (bhukarṇa prati hasta mānāya) daśāṅgulam ati atitisthat.

   The perimeter of the Puruṣa which remains surrounding the Earth is 1000 × 2000 × 2000 (aṅgulas). It rests one angula away of the earth of radius of one hasta (24 aṅg).

2. *Kauṭilya gives three sets of iron balances with length of beam and corresponding weight.*

   For first set, length of the beam = 8 aṅg, weight = 1, ironpala = 48 māṣa, and diameter = 1, then density (D) in māṣa per unit anguli is expressed as

   $\pi ({}^1/_2)^2 . 8. D = 48$

   $So, D = \frac{24}{\pi} = 24 \times \frac{7}{22} = 7.64$ [*taking* $\pi = \frac{22}{7}$]

   So the density of iron = 7.64 māṣa per cubic aṅgula. Similarly density for other sets is calculated by method of average.

3. *Sarva dhātunām gaurava vṛddhau satvavṛddhiḥ !*

   "The increase in density is increase in matter/price of all metals of equal volumes".

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Social Factors In The Development Of Technology

ARUN KUMAR BISWAS

Introduction

A presentation of the subject covered under the title would necessarily be tentative rather than exhaustive for several reasons. Since we would start with pre-historic India, the period under coverage is indefinite in the beginning. The end of the period is also indefinite since there are controversies as to when the 'ancient' period in India ended: the decline of the Gupta empire, the death of Harṣavardhana or the advent of Islam in India (we accept the last, i.e. the 'medieval' period being assumed to start at 1200 A.D.).

The complete history of such a vast indefinite period, for a vast sub-continent with ill-defined geographical borders, such as India, is yet to be written. It is doubtful whether such a 'complete' history would ever be written. A 'concise' history of Indian science in the ancient period, compiled by the Indian National Science Academy (INSA), has merely provided conceptual framework for further investigations and elaborations. The said compilation could not separately deliberate on 'technology' which we define as applied sciences related to natural and synthetic materials; nor could it adequately touch upon the philosophical and social factors. Evidently these topics were left for future deliberations (Chattopadhyaya, 1986)[1].

To postpone the writing of history of science and technology till the general history is worked out in completeness, would be as absurd as to wait for the sea-waves to subside before a plunge is taken. Similarly no useful purpose is served by deferring an attempt to provide a philosophical and sociological basis to the growth of science and technology in antiquity.

Of course, only a conceptual framework or a paradigm may be provided, and we caution the readers that paradigms may not be immortal. History is a continuous re-assessment of the past and, like the physical science, the history of ancient India has been well-known to be a grave-yard of rejected paradigms. Fresh discoveries and thoughts on ancient India are of surprisingly modern vintage, and we would illustrate in this essay how our previous concepts on Pre-, Mature- and

Post-Harappan history are undergoing metamorphosis. As new facts emerge, we must be in continuous search for fresh and more plausible paradigms (Biswas and Biswas, 1989). The 'factors' underlying the origin and growth of science and development of technology are complex and subjects evoking controversies. This article therefore should be treated as preliminary position-paper articulating the present author's views on the interpretations of established facts, and raising questions rather than answering them decisively. We have drawn heavily from the writings of D.D. Kosambi, R.S.Sharma, Debiprasad Chattopadhyaya etc. and yet ventured very often to disagree with them, leaving the matter of drawing the final (?) conclusions to the future readership and posterity.

Our presentation is divided into several distinct parts:

(A) Pre-to Post-Harappan social evolution linked with technology
(B) The issues of the Vedic age, iron age and second urbanisation
(C) Five centuries in India before Christ
(D) Five centuries after Christ
(E) The issue of medieval decadence.

(A) Pre- to Post-Harappan Scenario

Mortimer Wheeler wrote in his book *Indus Civilization* (1968) that this civilization is a book 'whose first and last chapters are missing'. Intensive research and new findings made during the last quarter of a century have largely restored the missing chapters. As a matter of fact there has been a sea-change in our concept of Pre-, Mature- and Post-Harappan scenario.

Gregory L.Possehl has edited the proceedings of the 1979 Kashmir conference on Harappan Civilization attended and contributed by 49 world-renowned participants (Possehl, 1982). Forty papers were published; in the concluding paper, Robert H. Dyson, Jr. summed up the recent and profound paradigm changes in the study of the Indus Civilization (Dyson, 1982, pp. 417-27). He wrote :

"The specific paradigms which defined the study of Indus Civilization in the earlier years, and which must now be abandoned, include the concepts of: (a) a sudden and late origin, (b) a long period of widespread and static cultural uniformity, (c) a sudden and uniform collapse caused by (d) an invasion of the Indo-Aryans (with an assumed second millennium date)".

We may briefly mention the various justifications made by Dyson, quoting other reputed scholars, while discarding the four above-mentioned paradigms. We may also add some of our own observations.

(a) Jean-Francois Jarrige's presentation of the discoveries (1977) at Mehrgarh (also spelled Mehargarh), Kachi District, Baluchistan, documented (Jarrige, 1982, pp. 79-84) the introduction of a subsistence economy to the north-western part of India well before 5000 B.C. Later Jarrige reported 'the first coarse ware' of the neolithic settlement dated sixth millennium B.C. and the early graves of the 7th millennium B.C. showing shell, turquoise, lapis lazuli, beads, pendants and sacrificial young goats buried with the dead (Asthana, 1985, *See* Foreword by

Jarrige). There were also the Mother Goddess human figurines. These indicate very early cultural contacts with Iran, Afghanistan and maritime people and development of the Mother Goddess sacrificial cult. Workshop for soapstone beads show sixth and fifth millennia craft specialisation and beginnings of long distance trade. The needs of agriculture caused increasing population in the alluvial areas. During the first half of the 4th millennium B.C. cylindrical jasper drills were evolved to serve the bead factories, and copper metallurgy was initiated, as evident from crucibles of the period containing some copper adhering to the walls. The latter evidence demolishes the hypothesis proposed by D.P. Agrawal (1971) that 'the metallurgical know-how had already diffused from Iran, hence we get in the Harappan culture (3rd-2nd millennia) a full-blown technology right from the beginning'.

The basic pattern of craft specialisation, mass production of potteries, terracotta figurines etc. at Mehrgarh clearly preceded the Mature Harappan Period. This is in consonance with Kenneth Kennedy's interpretation of the human skeletal evidence that there had been a stable population in the north-western part of the sub-continent for several millennia prior to the Harappan period (Kennedy, 1982, pp. 289-295).

The early settlement in the north-west was aided by the topography: gentle hills not too far from rivers, absence of dense forest, nearby maritime route for trade, pasture land and land suitable for cultivation of cereal crops. In such a topography, the earliest Indian civilization flourished at least several millennia before Iran developed village cultures. Shashi Asthana has rightly commented:

"The Indus civilization was conceived locally in the court- yard of one or more of the Pre-Harappan cultures - Baluchistan was not only a nuclear zone of several Pre-Harappan Cultures (Amri, Kot Diji, Sothi), it also served as a barrier to mass infiltration of the West Asian cultures. Some feeble alien waves did come but soon got assimilated" (Asthana, 1985). A chapter in Asthana's book is appropriately titled "The Collapse of the Irano-Centric View".

Further work is necessary so that the following problems are resolved. What was the precise origin of the Pre-Harappan Sothi culture which thrived in the Sarasvati valley? Were there specific influences towards it from the earlier Ganga-Vindhya (6570-4530 BC C-14 dates) and Bagor-Puskar neolithic traditions? The Ganga-Vindhya Culture did not spread like the Mehrgarh tradition; was it on account of the formidable dense forest in the Gangetic valley?

Before the onset of the third millennium B.C., the Ganeswar - Jodhpura complex (around Jaipur district, Rajasthan) started to feed the Pre-Harappan Sothi, Kalibangan I and Mature Harappan cultures with chalcolithic materials (Agrawala and Kumar, 1982, pp. 125-34). The Sarasvati - Hakra river route (not extinct in the Colistan desert, Pakistan) was studded with Pre-Harappan settlements of artisans who specialised in fabricating intermediate and finished chalcolithic (copper and bronze) products. Thus there is enough evidence to suggest that the Mature Harappan civilization did not originate suddenly. The Harappan culture was indeed indigenous, synthetic and gradually evolved, and this permitted regional diversities and cultural interactions within and across its boundaries, without its central character being lost. We do not yet know how the concepts of planning the cities, trade infrastructure and central control emerged in the Early Harappan millieu. We

are seriously handicapped by our ignorance of the Harappan script. But in the technology sphere, we may well imagine that the emergent urban culture, based on indigenous Pre-Harappan tradition, triggered new innovations such as the lost wax process of casting, diverse uses of minerals and metals, some imported and most locally processed.

(b) Despite broad similarities, common seals, the use of standard bricks and weights, specific patterns of city layout etc., the heterogeneities in Harappan settlements clearly indicate diverse components in culture and tradition. Subsistence patterns were different in the major sites: wheat and barley at Mohenjodaro, Chanhudaro and Harappa; barley at Kalibangan; and rice and millet at Rangpur and Surkotada. Sacrificial altars appear to be absent at Mohenjodaro and Harappa (which show Pasupati cult and Mother Goddess figurines as at Mehrgarh) while present at Lothal and Kalibangan.

Mature Harappan sites indicated different funerary practices. At Kalibangan, the cemetery yields abundant evidence for heterogeneous funerary practices with mutually exclusive areas. Social differentiation was strongly indicated. The Hakra river settlements were under Mature Harappan control.

The transition of Kalibangan I to Kalibangan II indicates intrusion of the central Harappan authority and culture into a predominantly rural and agricultural millieu. Similarly the full- bloomed Indus culture made its appearance at Banawali (Hissar district, Haryana) with 'proverbial dramatic precocity' bringing in gold, etched carnelian and lapis lazuli jewelleries, seals and weights of merchants, Mother Goddess figurines, objects of copper, arrowheads, spearheads, sickle blade, double spiraled pins, fish hooks etc. This place was evidently an important trading center along the Sarasvatī river, with well-demarcated acropolis and downtown, inhabited by Ṛgvedic *paṇis*.

Chanhu-daro was a bead manufacturing centre. Whereas Mohenjo- daro must have been the capital, showing prolific varieties of metals and gem minerals, Harappa was more of a manufacturing centre containing many more furnaces and exhibiting specialities not found at Mohenjodaro - such as coral, mica, yellowish limestone, yellow arsenic. The last item is interesting; Harappan copper was often heavily alloyed with arsenic (to substitute scarce tin, scrap bronze pieces were carefully stored in jars) whereas Lothal copper had no trace of arsenic.

Thus the previously held notion of 'static cultural uniformity' in the Harappan sites needs very serious alteration. Of particular importance is the cluster of Sarasvatī valley sites which showed pre-Harappan Sothi-type trends, earliest agricultural fields, and despite intrusion of Harappan potteries, seals and artifacts, undeniable evidences of Rgvedic sacrificial altars and social stratification. The Harappan civilization represented unity and diversity. The Rgvedic culture on the banks of Sarasvatī river network (mistaken as alien Aryan intrusion) belonged to the Indus civilization in the wider sense and yet represented very special features particularly sacrificial altars, pastoral cum agricultural community suffering economic exploitation in the hands of Ṛgvedic *paṇis* coming from the Indus valley. The Ṛgvedic strife was a civil war between tribes speaking the same language but different dialects. The Aryan- Dravidian theory is an over-statement of the reality.

(c) The Harappan civilization did not collapse suddenly or uniformly. The field evidence shows that the decline was irregular, long-drawn and caused by different factors in different areas. These factors included changes in coast-lines, repeated floods in the Indus valley, the drying up of the Sarasvatī-Hakra river system due to drought and tectonic changes, collapse of the Ur and Sumer civilizations (the trade with which had sustained the technologies in and around Mohenjodaro), civil strife and so on. Probably all these factors contributed to the slow but inevitable downfall of the first urban civilization in India.

The major shift of population due to the drying of the Hakra (or Sarasvatī) river (Mughal, 1982, pp. 85-95) was certainly of crucial importance. A significant population moved east from the Hakra area into Haryana and Uttar Pradesh; this is attested by the number of sites in this region going up from two to three in the Mature Harappan to sixty or more afterwards. Harappan potteries were gradually replaced by PGW in the Ganga-Yamuna valley.

There was also a perceptible shift towards the south. New Harappan sites without antecedants came up in western central India. Bronze technology was transmitted to Daimabad. The Harappan technology was persistent and prolonged in Gujarat. A nexus was established between the Harappan culture in Gujarat and the Ahar Chalcolithic culture around Udaipur in Rajasthan. It is most probably the Ahar people who mined zinc ore in the Rajpura- Dariba mine (C-14 dates 1260 B.C., 1136 B.C. etc.) and pioneered the making of cementation brass (an effort to substitute tin in bronze) which was definitely used in Lothal and later at Atranjikhera (Biswas, 1993).

Like the first chapter of the Harappan civilization, the last chapter of the 'book' is also likely to be deciphered and written in greater detail.

(d) Writing on the recent paradigm changes, Dyson's fourth and last point related to the so-called 'invasion of the Indo- Aryans in the second millennium'. He observed :

"The invasion thesis becomes a paradigm of limited usefulness. There is a continuing lack of agreement over the criteria by which the presence of the Indo-Aryans can be demonstrated and, even more surprisingly, an absence of a rigorous analysis of available archaeological evidence against the cultural content of traditional Vedic literature" (Dyson, 1982, 417-24).

The skeletal record is mute and does not suggest any large scale massacre or the intrusion of any new race in the Harappan civilization (Kennedy, 1982, pp. 289-95). Dales questioned: "Where are the burnt fortresses, the smashed chariots and the bodies of the invaders"? (Dales).

The history of the Indo-Aryans continues to haunt the study of Harappan civilization. At Kalibangan we find the Vedic sacrificial altar in a Harappan millieu. Lamberg-Karlovsky, Fairservis and many other scholars had to accept that the Indo- Aryans could have been in the Indus Valley a thousand years before the end of the Harappan civilization.

Brain-washed by the linguists, the archaeologists vainly look for the evidence of Aryan intrusion. Jim G. Shaffer however writes categorically :

"Current archaeological data do not support the existence of an Indo-Aryan or European invasion into South Asia at any time in the pre-or proto-historic periods. Instead, it is possible to document archaeologically a series of cultural changes reflecting indigenous cultural development from pre-historic to historic periods. The early Vedic literature describes not a human invasion into the area, but a fundamental restructuring of indigenous society that saw the rise of hereditary social elites.

"The linguistic similarities (between the Indo-European languages) that are cited as proof of these human invasions have alternative explanations — What was theory became unquestioned fact. It is time to end the linguistic tyranny" (Shaffer, *see* Lukacs, ch. 4, pp. 77-90).

The present author elaborated the theme in his 1990 essay on *The Aryan Myth* (Biswas, *see* Ray and Mukherjee, 1990, pp. 29-47) quoting Professor H.D. Sankalia's letter (dated 10 October, 1986) written to him:

"These theories (of Aryan intrusion) cannot be proven, unless definite knowledge regarding script, language etc. can be had—. The old problems, first raised in 1930, have remained unsolved".

The problem is artificial and falsely created. Like Shaffer, the present author also asserted (Biswas, *see* Ray and Mukherjee, 1990, pp 29-47) that the archaeological and literary (Vedic) data are easily correlated in terms of the obvious and alternative paradigm namely that the Ṛgvedic culture was autochthonous in the Sarasvatī valley overseeing the Indus valley civilization. These were indeed sister civilizations. At sites like Kalibangan and Bhagwanpura, the Ṛgvedic culture was Pre-Harappan which, in the words of B.B. Lal, 'formed the base on which the Mature Harappan appeared like bubbles on a vast lake, only to disappear and merge into the waters of the lake itself (Lal, *see* Possehl, 1982, pp. 335-38).

Social factors underlying first urbanization

It is difficult to make firm statements on the subject except that the gravitation of diverse cultures (with strong technological components) towards Mohenjo-daro, Harappa and Kalibangan was a long-drawn process. The motivations were essentially economic with some theological overtones.

Stone, copper and bronze implements were used, and therefore Harappan era could be characterised as bronze age. Bronze was used more for decorative and agricultural/production purposes and less as a raw material for warfare. Hoes and celts must have been used for cultivating annually inundated Indus valley agricultural fields. Technology was sustained by agricultural surplus as attested by the huge brick-built granaries.

Several kinds of technologies such as gold, silver, copper, bronze metallurgy, pottery and bead industry flourished on the basis of well-established furnace technology. Sun- and fire-baked bricks had been evolved much earlier in the Mehrgarh culture, R.S. Sharma writes: 'obviously the laying out of towns with intersecting streets and perfect drainage system, and the erection of houses all made of burnt bricks, must have required a huge staff of bricklayers, masons, wood-cutters, charcoal burners, metalsmiths, engineers, a fact which bears

testimony to the great organizing feat of the Indus valley people' (Sharma, R.S. 1983).

The other means of livelihood were cotton-growing, textiles, carpentry, river-and sea-based trade. Although magic, theology and priestcraft played strong roles in the society, the overriding power structure specialised in trade and its efficient management. The earliest specimens of writing on seals were probably meant for book-keeping. The use of uniform weights ensured standardisation and control over the huge Harappan network. The theological component of the culture promoted the studies of astronomy and geometry which were sustained in the Rgvedic and later Vedic cultures after the collapse of the Indus valley civilization.

(B) The Vedic Age, Iron Age and Second Urbanisation

Chattopadhyaya insinuated that 'one reason for the objection against the theory of Aryan invasion... seems to be frankly chauvinistic, (Chattopadhyaya, 1986, pp. 360-371). The present author countered the charge by quoting the internationally reputed scholars (Biswas and Biswas, 1989, Biswas 1990. The possible objections to the newly emerging paradigm (Dyson's beautiful summary outlined in detail in the previous section (A) of this article) were also successfully met (Biswas, 1990, pp. 37-45).

One of the possible objections has been that the Rgvedic civilization was rural and could not have anything common with the urban, Harappan tradition. This objection merely illustrates 'the absence of a rigorous analysis of the Rgvedic literature' as mentioned by Dyson (1982) and quoted earlier. The Rgvedic god Indra, 'the destroyer of cities', merely symbolized the tillers and pastoral people taking up arms and using horses against the oppression perpetrated by the urban rulers and plunderers coming to the Sarasvatī valley from the west and the south. Hundreds of cities were no doubt destroyed by the Ṛgvedic warriors (archaeological excavation revealed the burning of the Harappan site Surkotada) (Shaffer; *see also* Lukacs, pp. 77-90), but the victor Divodāsa himself became the ruler of a few such cities (*ṚV*. 4.26.3) specially of those made of *aśma* (stone) (*RV*. 4.30.20). The Ṛgvedic people knew palaces 'with many pillars' (*ṚV*. 5.62.6) and 'many doors' (*RV*. 7.88.5). They adored efficient city administrators (*RV*. 1.173.19). Kalibangan, the third important urban centre of the Harappan civilization, flourished on the confluence of the Sarasvatī and Dṛṣadvati, and has been widely claimed as a Rgvedic site.

In the semi-urban surroundings, the Ṛgvedic agriculturists, carpenters, wheelwrights, weavers (of wool), leather workers, blacksmiths, medical men, poets and rich men (traders) lived together; the blacksmiths used to approach the rich people (*hiraṇyavantam*) and offered to make for them metallic artifacts and ornaments (*ṚV*. 9.112.2, 10.53.9 etc.)

The *Ṛgveda* described in part the chalcolithic culture in the foothill of the Sivalik mountains extending along the valleys of the Sarasvatī river system. It notes the Pre-Harappan transition from the neolithic to the chalcolithic period : *aśmanmayi vasi* (10.101.10) or stone-made implement to *vasim ayasim* (8.29.3) or metallic axes. In the very first hymn (1.1.1) the text eulogizes fire as *ratnadhātamam* or

cradle of gems meaning gold, silver or copper. We have noted in the Rgveda the following words/items related to minerals and metals (Biswas, Chakravarty and Biswas, pp. 49-66):

Jewel, grinding or sharpening stone, metalsmith or black- smith, bellows blowing air, melting gold or metal, sharpening metal. Gold, golden necklace, head ornament, ear-ring (*hiraṇya-karṇa*, 1.122.14), coin, silver, anklet, ring, breast-plate, bangle, copper (*ayasmaya tamba*, 5.30.15). Metallic leg, razor, bucket, cymbal, javelin or lance, lute, needle, scissor, sword, knife, sickle, ploughshare, shield, metal stick used for roasting meat, cooking vessel etc. The references to the blacksmiths, bellows, melting of metals and many artifacts of gold, silver and ayas (probably copper and bronze), and also of traders, river navigation, urban games like dice-playing, multi-storey buildings etc. clearly signify that the authors of the Rgveda were quite familiar with the urban life of the Harappan standard, notwithstanding their preferences for rural simplicity and religious fervour.

In his legitimate attempt to glorify the Harappan civilization, Chattopadhyaya has unnecessarily sought to underrate the scientific contributions of the Rgvedic civilization. He writes:

"The concept of *ṛta* - containing the idea of the laws of nature - could never have occurred to the Ṛgvedic poets as ordained by any omnipotent Divine Creator for the simple reason that the mono-theistic theology was totally unknown to them" (Chattopadhyaya, 1986, p. 392).

This is indeed strange! Chattopadhyaya has missed Ṛgveda's clear message on the unity of Godhead and monotheism (1.89.10, 1.164.46, 3.55.1-22, 8.58.2, 10.82.3 etc.) and its clear statements that 'one *ṛta* exists everywhere' (4.40.5) and 'one Indra appears differently through illusion' (6.47.18)? He made another sweeping generalisation when he wrote:

"Only one among the many philosophical trends in India, namely Vedanta was keen on denying logic and rationalism in order to make room for an abject faith in the scriptures" (Chattopadhyaya, 1986, p. 47).

Chattopadhyaya conveniently ignored the scientific (and even agnostic) spirit of the Nāsadīya Sūkta (*ṚV.* 10.129.1-7) which raised the issue of the created world and wondered whether any intellect is in possession of all the knowledge about the created world. The Vedic world-view started with the spirit of enquiry and search for the truth. Ofcourse theological fundamentalism and the evils of casteism and priestcraft crept into the Indian society, but we should not forget that the entire phenomenon took place more than three millennia before the public humiliation of Galileo before the Inquisition. We have endorsed Chattopadhyaya's basic thesis of a dialectical struggle between reason and anti- reason in the Indian thought-world *with the rider* that this struggle existed in all civilizations, and exists even to-day down to the psychological plane of an individual (Biswas and Biswas, 1989).

The dark period of Indian pre-history viz. the second millennium B.C. may best be described as the period of mass migration and re-formation of the Indian Society. The Rgvedic strife did not represent any conquest by the alien; it was a civil war ultimately won by the peace-loving, oppressed agriculturists living in the north-eastern part of Haryana/Punjab and not by horse-riding barbaric outsiders.

The defeated tribes left India through Afghanistan and Iran, and were later known as the Zoroastrians; this is proven by a sudden extinction of the Harappan sites in Baluchistan and Afghanistan around second millennium B.C. Within a few centuries, the Sarasvatī valley people moved eastward on account of drought and shift in the river bed due to tectonic movement. They were in search of perennial water or *sadānīra.*

At first they moved along the Himalayan foothills avoiding the Gangetic valley covered with dense forest. Later they were able to clean the forests by using fire and iron implements, The Indus valley people moved towards Gujarat and Central, Western and Peninsular India.

Archaeological excavations have established that chalcolithic cultures existed in the Central and Western India continuously from 2000 B.C. to 900 B.C. Three successive cultures - Kayatha, Malwa and Jorwe arrived on the scene with typical pottery styles. The traditions of pottery styles, copper and bronze castings, bead manufacture etc. might have been introduced by the migrating Harappans. On the other hand, the great visibility of the megalithic cultures in Peninsular India and the onset of iron age in Karnataka region around 1200 B.C., without much of a chalcolithic background, indicate predominant indigenous traditions devoid of any Harappan precedence.

In the eastern India, Copper Hoards people had developed copper metal technology sometime before 1500 B.C. Using Singhbhum area ores the artisans could smelt high grade copper; they knew closed casting, alloying by arsenic and lead, annealing and cold work for hardening the tools (Agrawal, 1971, pp. 205, 242; Agrawal, 1982, pp. 213-214).

Probably this technology was developed by itinerant smiths moving from Bengal-Bihar area to the Gangetic Doab in Uttar Pradesh, the artefacts becoming more sophisticated in the latter area. The anthropomorphic figures developed by them could be either ritual totem or missiles or simple scarecrows.

The tradition of itinerant smiths was probably a common feature of most cultures in the ancient world. The metalsmiths at Harappa used to receive intermediate ingots from the smiths around the Hakra river who probably got the smelted copper from Ganeshwar- Jodhpura area in Rajasthan by the river route.

The same river route enabled supply of copper-made fish hooks, mirrors, bangles etc. to Kalibangan where the last stage of fabrication might have been made. The Rgveda also records (9.112.2) an itinerant smith looking for a customer to sell his metal-tipped arrow.

The chalcolithic culture people in the West Bengal sites of Pandu Rajar Dhibi, Mahishadal etc. used pre-PGW ochre washed potteries and had cultural contacts with chalcolithic Central India (Malwa and Navdatoli), South-East Asian countries such as Thailand and most importantly the PGW-developing people coming from the Sarasvati valley and representing the Vedic tradition (Dasgupta, 1967, p. 896).

S.P. Gupta beautifully summarised the phenomenon of cultural contacts:

"The period of second millennium B.C. in India is not as 'dark' as was thought a couple of decades back. Broadly speaking, the western regions had the late phase

of Harappan culture, the southern regions the neolithic-chalcolithic complex and the eastern region the hoards" (Gupta, 1963; 1965, p. 896).

A fusion of the three traditions must have taken place during five centuries 1500-1000 B.C. while Indian sub-continent entered the Iron Age and the period of second urbanisation. Though of uncertain dates, the Indian epics described Rāma's cultural contacts with the eastern and southern civilizations and Kṛṣṇa establishing some cultural hegemony across the sub-continent prior to submergence of the Dwarka township, an event which has been recently attested through marine archaeological recovery of the artefacts and their thermoluminescence dating.

The Iron Age and Second Urbanisation

The present author has presented elsewhere (Biswas, 1991, ch. XII) elaborate and critical discussions on the onset of Iron Age in India. Discovery and use of iron started around 1200 B.C. indigenously in at least three nuclear zones - Karnataka in the south (e.g. Komaranhalli, 1200-1100 B.C.), U.P. Rajasthan area in the north (chalcolithic Ahar transmitting the tradition of furnace technology and first iron in the neighbouring Atranjikhera site in U.P. C-14 dated 1155 B.C.) and West Bengal-Bihar area in the north-east (partially reduced iron oxide in Pandu Rajar Dhibi, 1250 B.C. and carburized iron celt showing pearlite in Barudih site dated 1200 B.C.).

The above data clearly suggest cultural contacts between the three nuclear zones and indigenous diffusion of iron technology from one zone to another. The remote possibility of Sialk VI iron-making tradition (which flourished only after 9th century B.C.) influencing the whole of India through the immigrant Aryans' (Banerjee, 1965) may be safely ruled out. There are enough evidences of early experimentation, imperfect solid-state reduction, wastage of iron in the slag etc. in the sites of each of the three nuclear zones to justify the theory of indigenous origin.

The metalsmiths of Komaranhalli and Tadakanahalli evolved lamination technique (alternate layers of non-carburised wrought iron and carburised iron) (Agrawala, Narain and Bhatia, 1990), centuries before the appearance of the earliest known (outside India) laminated object (Egyptian knife, 900 B.C.).

Social Factors in Pre-historic India

As we approach the 'historical period' in ancient India, it may be profitable to dwell on the title of the paper: 'Social Factors in the Development of Technology in India'. The earlier scholars, plagued with the paucity of data, erroneously presumed that the Harappan technology 'suddenly' developed, probably imported from Iran. While advocating the indigenous model, we do not ignore *the factor of gradual diffusion* of scientific knowledge and technical know-how through trade contact. As a matter of fact, we insist that technological development and urbanisation (a related phenomenon) have often been sparked by trade contacts with other cultures.

Pre-Harappan and Mature Harappan India exported through trade routes, ivory, carnelian beads, conch-shell products, copper and bronze artifacts and even cultural components like the concepts of gods - Varuna and Mitra, and the linguistic

loan-words (Altin Depe of Central Asia was a Harappan outpost). In return, tin, turquoise, lapis lazuli etc. used to be imported. Traders assisted in the two-way diffusion of culture and technology. Large scale racial intrusion or invasion (long before Alexander's era) must be regarded as a mythical concept unless positively proven.

How the technologies were invented in Harappan India can only be surmised and never conclusively proven. The Harappan script has not been deciphered, and the 'social factors' can only be a matter of conjecture.

Gordon Childe deliberated on the phenomenon of 'urban revolution' in the ancient world and the 'ten criteria' which accompany it (Childe, 1950; Possehl, 1979). He also mentioned that one trait of urban revolution was the creation of 'exact and predictive sciences' such as arithmetic, geometry and astronomy. Childe could have included material technology (not science) as one of the traits of early urbanization. Though widely quoted, his 'criteria' or indices are 'delineatary rather than explanatory'. His analysis evokes many subsidiary questions. Why the agricultural surplus does not always lead to the formation of cities, and how did some ancient cities (like Mathura) prosper without any agricultural surplus in the immediate neighbourhood? What induces the emergence of a ruling class to dominate over a city? What provides sufficient driving force for artisans to move from the rural to the urban environment?

It appears that a critical measure of trade, cultural and even military contacts with neighbouring states provide vital stimuli to the growth of civilizations, cities and technology. This factor has been overlooked by many scholars including Childe. Ecological and military factors (civil war) must have damaged the Harappan civilization, but its collapse was ultimately due to the loss of short-range and long-range trade links.

The phenomenon of the second urbanization in India (beginning in the early part of the first millennium B.C.) was *not* totally unrelated to the first urbanization, despite the contrary claims of the earlier scholars. The migrants from the Indus and the Sarasvati valleys took long time to acclamatise and rehabilitate themselves in the unfamiliar terrains of hills and forests inhabited by un-friendly people. But they carried with them traditions of pottery, beads of semi-precious stones, artifacts made of copper and its alloys and so on. At Bhagwanpura, we find Harappan pottery and Painted Grey Ware side by side and no broken skull (Lal, vide Possehl, 1982). The fact of continuity of Indian civilization, even through the 'dark period' of second millennium, cannot be wished away. The excavation at Atranjikhera in western Uttar Pradesh indicate (Gaur, 1983) a continuous transition from 1400 B.C. - at first the Aharian chalcolithic culture using BRW pottery, copper alloys and even brass, and gradually evolving PGW, glass and (the wonder metal) iron technology. The recovered ecological and political stability once again made the conditions ripe for the emergence of power structure, trade contact, new technology and urbanization.

The Role of the Iron Age

The issue of the Iron Age influencing second urbanization in India has been widely debated. R.S. Sharma suggested that the discovery of iron resulted in speedy clearance of forest, more extensive cultivation through the use of iron ploughshare, accumulation of large agricultural surplus and formation of city- states. This model has been criticised on many counts.

Iron was discovered as early as 1200 B.C., but its widespread use in the Gangetic valley did not start, according to Sharma himself, before the sixth century B.C. The artisans in the Rajasthan-Uttar Pradesh area took many centuries to standardise reduction-smelting, lamination and fabrication of iron artifacts, and they did not have sufficient good grade iron ore for mass production. Kosambi had pointed out that the spurt of iron technology in India had to wait till the Vedic cultural people crossed the Ganges in Bihar, moved south and gained proper access to the iron ore deposits (Kosambi, 1965).

Prakash and Tripathi have meticulously noted (Prakash and Tripathi, 1986) that the early PGW-era iron tools were war implements like spear heads, arrow heads, dagger, knives, and building materials like rods, pins and nails. Only a few agricultural tools e.g. axes and sickles were made in iron. Spades and ploughshares came much later. Thakur asserted (Maity, Thakur and Narain, 1988) that iron implements such as axe, plain or socketed, hammer and ploughshare were conspicuous by their rarity, if not absence, even in the 500 B.C. NBP sites; this fact negates Sharma's hypothesis. Furthermore, A. Ghosh pointed out (1973, specially ch. III) that the clearance of forest, done in the epic/PGW era was more by the use of fire rather than iron implements. Cultivation used to be done more by hoes, sickles and wooden ploughshares tipped with iron rather than iron ploughshares and axe which became popular only around 4th/3rd century B.C.

Agricultural surplus was no doubt generated during the early part of the first millennium B.C., supporting non-agricultural crafts. But this did not by itself promote urbanisation. Debiprasad Chattopadhyaya has included in his book (1991) two invited articles written by Ranabir Chakravarti (Chattopadhyaya, 1991, Appendix I, pp. 305-350) and N.R. Banerji (Ibid, pp. 371- 396) which touch upon the above issues. Chakravarti and Banerji tend to support the criticisms against Sharma's model.

We propose that the emergence of the new technologies and the Iron Age was one amongst many factors underlying second urbanization. Besides, this was a cyclic relationship, urbanization further promoting iron technology. Was there a deeper cause promoting both? Ghosh accorded priority to the social need/political demand for surplus rather than the capacity to produce the surplus as a result of technological innovations (Ghosh, 1973). His argument was in favour of the greater role of a 'power structure' without which a surplus could not appear the moment it is asked for (Chakravarti, 1991, pp. 305-350). The megalithic culture in the Peninsular India produced iron and agricultural surplus, and yet no urban tradition.

Following the leads provided by Childe, Sharma and Ghosh, we may try to go deeper into this problem. What causes the emergence of a 'power structure' articulating 'socio-political needs'? Basically it is a psychological drive-against

complacency and for consolidation of existing resources and distribution mechanism by centralisation; it is also promoted by an expansionist urge to meet shortage of resources by trade or conquest, and even cultural expansionism viz. to propagate one brand of religion or culture. This urge could be articulated in the ancient world as physical/social/political 'needs' only when there was an opportunity, when there were trade contacts with the neighbouring states. This reality of psycho-physical situation promoted in the ancient world - and still promotes in the modern world - urbanization and breakthroughs in new science and technology simultaneously. Ultimately, urbanization and technology activate each other in a cyclic fashion, Chakravarti pointed out (Chakravarty, 1991, pp. 305-350) that urbanization also meant new ideas and a revolt against tradition and conservatism.

We propose that the situations as enunciated in the previous paragraph must have ripened prior to the first and, a millennium later, the second urbanization in India. The Yajurveda referred to not only gold, silver, copper, bronze, tin and lead, but also the newly discovered iron, the black metal - *śyāma* or *kṛṣṇāyasa* (*Śukla Yajurveda* 18.13). *Bṛhadāraṇyak Upaniṣad* (3.9.18) mentioned a tong handling hot charcoal, and in *Śatapatha Brāhmaṇa* (Śat.Br), we find references of leather bellow blowing air into a furnace, blow-pipe used by the smelter and so on (1.1.2.7, 1.6.3.16). Sat.Br also described a large number of iron implements and the emergence of gold-based money economy: 'with gold they do nothing, and yet it is an object of respect' (5.5.5.16). Even lead was used as a medium of barter (*Śat. Br*. 12.7.2. 10-12). Heavy pieces of lead were used in the art of weaving. Barley and rice were traded for lead (*Śat. Br*. 12.7.2.10); sheep's wool was also used as a medium of barter for obtaining grain and other commodities (*Śat. Br*. 12.7.2.10).

The late Vedic literatures clearly describe the prominence of the non-agricultural professionals: smelter, smith, carpenter, cloth manufacturer, leather worker, potter and jeweller etc., who could thrive only on agricultural surplus and some kind of administrative protection and control.

International trade seems to have started a millennium after the collapse of the Harappan civilization and before the 'historical period'. Around 1015 B.C., King Solomon of Palestine received from Ophir - now identified as Sauvira in the Gulf of Cambay - gold, silver, ivory and peacocks. Homer reported trade with India. Thus the process of second urbanization in India had started right in the beginning of the first millennium B.C. through initial trade contacts and gradual territorial expansions.

Around 1000 B.C., Hastinapura settlement brought in from outside agate and carnelian beads, and the first settlement of Taxila started at Haithal. *Chāndogya Upaniṣad* refers (5.11.5) to a *janapada* or township in which there is no liquor or adultery. It is quite evident that the late Vedic era (1000-600 B.C.) initiated the establishment of the famous (sixteen) *mahājanapadas* or states most possibly sometime during the 7th-6th century B.C. period.

During the latter half of the sixth century B.C., the Persian king Cyrus had made an unsuccessful onslaught on India. During this time, Ujjain in India became a leading centre for the manufacture of iron war implements. The king Pradyota, contemporary to Gautama Buddha, ascended the throne of Ujjain around 528 B.C.

He attacked Kauśāmbi and Taxila years before the Persian king Darius occupied Taxila in 518 B.C. For many decades thereafter, the Persians used to take Indian gold, precious stones, brass, iron-tipped arrows and even Indian soldiers to assist them in their fights against Greece. Pythagorus might have visited the Jain settlements in the Western India during this time. The second urbanization took place in India amidst a clearly emerging international backdrop.

The social factors underlying the nascent urban technology included the new geographical-cum-geological scenario. The sophistication of iron technology in the Bihar sites like Rajagriha was essentially on account of the proximity of iron ore deposits in the Singhbum area (Kosambi, 1965), which also produced alluvial washings of gold (the name of the river 'suvarṇarekhā' is suggestive).

Hegde has adduced conclusive proof for the geographical /geological basis regarding the development of the successive categories of potteries (1200-300 B.C.) in the Ganga-Yamuna basin (Hegde, 1987). Thick deposits of ferruginous, plastic, secondary clay in this area were laboriously elutriated to produce 10-100 μm clay particles, free from the larger and heavier particles (of feldspar, quartz, limestone etc.) and paste of this was used to produce the famous PGW or Painted Grey Ware. The black pigment on BSW (Black Slipped Ware) corresponded to magnetite (Fe_3O_4).

Evidently the sun-dried ware was painted with a suspension of finely ground red ochre (Fe_2O_3 as such or hydrated) which was locally available, and then baked in reducing atmosphere, surrounded by cowdung cakes in *gajapuṭa* fire.

Lastly, the Northern Black Polished Ware or NBPW also showed under an electron microscope opaque crystals of magnetite (produced similarly) in a background of amorphous glass-like matrix which assayed 11-13 p.c. Na_2O and 2-4 p.c. CaO. For producing this glassy glaze, *sājjimāṭṭi* or reh, the alkaline, natural efflorescence, profusely found in the Ganga valley, chiefly in the mid-eastern and eastern Uttar Pradesh and Bihar, was used (Hegde, 1987). This *sājjimāṭṭi* assays 20-40 p.c. Na_2O, 50-70 p.c. silica and 5-10 p.c. lime. Availability and use of *sājjimāṭṭi* enabled the PGW people to produce not only the famous glassy glaze in NBPW but also the soda-lime glass (Hegde, 1987; Tripathi, 1976; Roy, 1986; Sen and Chaudhuri 1985). Very significantly Atranjikhèra and Hastinapura produced the earliest samples of glass in India. The Harappan people could produce faience but not glass.

Social Philosophy and Technology

The Ṛgvedic culture in the Sarasvatī valley shared many Indus valley traditions such as pottery and bronze-making styles, use of burnt brick, use of seals, binary and decimal digits for standardisation, geometry in altar construction, astronomy etc. The Vedic literature amply testified the spirit of enquiry. In the *Nāsadīya Sūkta* (*ṚV*.10.129), the origin of creation was discussed. The existence in nature of a self-supporting principle was inferred (*ṚV*.10.129.5).

In the *Atharvaveda* the genesis of conch-shell and pearl were speculated upon (4.10. 1-7). The *Śatapatha Brāhmaṇa* propounded a theory of material evolution (6.1.3. 1-5). *Kāṭha Upaniṣad* mentioned atoms and molecules (1.2.20). Uddālaka

Āruṇi a historical figure, who travelled from Taxila to North Bihar, and was mentioned in the *Chāndogya Upaniṣad*, was a materialist or hylozoist, who propounded that everything in the universe including man evolved out of three elements, and even mind is a product of matter. He preceded Theles of Greece by nearly two centuries, and has therefore been claimed by Chattopadhyaya to be the 'first scientist in the world'.

In the Vedic literature there are several references to applied science and technology. The *Yajurveda* mentioned the newly discovered black metal iron as well as glass (*kāca*), an ornamental article (Sen and Chaudhuri, 1985). *Chāndogya Upaniṣad* mentioned the then existing sciences of elements (*bhūtavidyā*) arithmetic (*rāśi*), mineralogy (*nidhi*) etc. The *Śatapatha Brāhmaṇa* described the smelting of gold, components of the smelting apparatus, the use of borax as flux, joining of different metals and so on. The Vedic culture also evolved the traditions of speculative logic on body and mind, and linguistics. The medical tradition of Caraka must have been initiated by the *vaidyas* of the Vedic period.

The positive sciences of the Hindus were thwarted to some extent by the retrograde institution of caste. Originally, there was the division oflabour but no hereditary caste (*ṚV.* 9.112.3).

Gradually, separation was introduced in the society by the dominating priestcraft, and this caused degeneration and the rise of *varṇāśrama* or hereditary caste (*ṚV.* 10.90.12). The white *Yajurveda* referred to the *vaidyas* (medical men) in derogatory terms.

At a time when the potters had developed beautiful PGW and NBPW potteries, the *Maitrāyaṇī Saṃhitā* prescribed (Kashikar, 1969) that the ritual milking pot should be prepared by one belonging to any of the first three social orders, but not by a potter of the lowermost caste! The *Śatapatha Brāhmaṇa* categorised people as well as metals in caste denominations (13.2.2.16-19, 13.3.4.5) : the upper caste gold was meant for kings and brahmins whereas the lower caste iron was meant for ordinary people. This trend of categorising even metals and other materials under the four 'castes' persisted for centuries. The Gupta era *Amarakośa* listed the metallurgical equipments under *śūdravarga*!, professional guilds, degenerated into sub-castes, the social barriers of which rarely permitted the necessary exchange of technical information amongst themselves or with the brahmin scholars who would keep the Vedas out of bounds from the lower caste artisans. It has been well-said that 'the evils that caste system engendered cannot be over-estimated'.

(C) Five Centuries in India before Christ

The process of second urbanization in India, initiated after the seventh century B.C., is well-described through the terms *jana*, *janapada* and *mahājanapada*, used by Pāṇini (dated around the middle of the fifth century B.C., Agrawala, 1953). Whereas *jana* meant a compact clan, the emergence of *janapada* was characterised by aggregation of people of different languages, faiths and professions (*Atharvaveda*, Pṛthvī Sukta, 12.1.45). Pāṇini equated citizens or *janapadis* as professionals practising different trades (*Aṣṭādhyāyī*, 4.1.42; also Yāska's *Nirukta* 1.1.5). Pāṇini's ten (later sixteen) *mahājanapadas* were big states with capitals in

the cities which promoted diverse trades such as those of potter, blacksmith, carpenter, barber, washerman, bow-and-arrow maker, weaver, blanket-maker, dyer, gem- maker and jeweller, miner, goldsmith etc. Patañjali wrote that each village must have the first five. The last few ones were closer to the cities and met the requirements of the king and the state. The literary and archaeological sources broadly agree in placing the innovative period of Indian coinage in the 6th-5th century B.C. (Mukherjee and Lee, 1988, vide Appendix on Emergence of Coinage).

The emerging power structures and rivalries promoted technology which was meant to protect and augment the power structures in return. As the *mahājanapadas* grew in size, the national and international boundaries came under dispute and military confrontation. We find 600 B.C. mud ramparts and the use of sun-dried and fired bricks in the fortifications of this era (600-500 B.C.) at Ujjaini, Eran, Kaushambi, Rajghat etc. The iron and weapon industries flourished simultaneously. The Persians intruded into a part of north-western India, took away some gold and brass, used Indian iron-tipped arrows against the Greeks and introduced Persian punched coins (*siglos*) into India. Precious stone industry was set up at Śrāvastī.

In the area of the civic amenities there were terracotta ring wells. At Sringaverapura was erected a brick-built storage tank with arrangement for settling and removal of clay.

In the intellectual world there were many dissenters to the Vedic culture. Apart from Gautama Buddha (563-483 B.C.), the Jainas, Ajīvikas and the materialists such as the Cārvākas or Lokāyatas protested against the Vedic ritualism and theological fundamentalism. The intense intellectual ferment resulted in speculative philosophy and logic (Seal, 1985).

Pāṇini (middle of the 5th century B.C.) not only elevated his work of grammar to the level of a science of languages but also deliberated on several scientific terms. *Padārtha* (*Aṣṭādhyāyī* 1.4.96) came to mean a well-defined material, and *sattva* meant the metallic essence (1.4.57). *Pramāṇa* indicated measuring standard, then authority and lastly scientific or logical proof (3.4.51). Pāṇini honoured the tradition of searching for truth by explaining that *upajñā* meant discovery of a new knowledge, not handed down by tradition. This new knowledge was supposed to give rise to a new enterprise or application, that is *upakrama* (2.4.21; 4.3.115 and 6.2.14). Thus, Panini laid the philosophical foundation of science and technology.

While accepting the roles in society of technology, economics and religion (Vedic), Kauṭilya (fourth century B.C.) laid maximum stress on *ānvīkṣiki* or the critically investigative philosophy. The obscurant force of ritualism and priestcraft tried its best to subdue the materialist tradition of Lokayata but the scientific spirit could not be exterminated.

The medical tradition of Caraka involved clinical observation, diagnosis and cure. This was initiated by Atreya Punarvasu and Agniveśa at Taxila, and the tradition persisted for centuries. Under Suśruta's care surgical instruments were invented, and in the post-Christian era, Nāgārjuna and others conducted alchemical experiments.

India was the first to obtain (on or before fourth century B.C.) pure zinc by reduction-distillation and use it for making high quality brass (Biswas,1993). During this period, hardened and quenched steel showing tempered martensitic structure was produced (Chattopadhyaya and De, 1989). Such remarkable technical achievements were made when indigenous efforts successfully withstood the challenges from the external world (Persian and then Greek).

The Nanda empire (354-324 B.C.) based in Pataliputra did spread into the Peninsular India in the south, but a pan-Indian situation developed only during the rule of the Maurya dynasty (322-200 B.C.). To ensure protection against enemies and also hegemony and prosperity in their vast empire, the Mauryas introduced state-controlled economy. This promoted rapid growth of mining, metallurgy, semi-precious gem and bead industries (such as at Sonkh), weaving industries (at Mathura, Varanasi, Baṅga, Kaliṅga etc.). Weights and measures were standardised.

Kauṭilya's *Arthaśāstra* (*AS*) described in detail the mining and metallurgical practices as well as the elaborate tax and levy structures which met the diverse needs of the state. The lists of dutiable articles included practically everything, from flowers, vegetables, fruits etc. on the one hand to, diamonds, pearls, and other precious stones on the other (*AŚ.* 2.22.4-7). The object was to control the turnover of all goods and maximise state revenues (Kangle, 1986).

Since the administration was not repressive, the all- pervasive control improved innovation and standardisation in the technical crafts. We find in this period hoards of punch-marked silver coins, well-designed urban layouts (such as at Sisupalgarh), beautifully chiselled sandstone monuments etc. The enlightened administration allowed in a limited and controlled manner, private ownership of land provided it did not have any mineral resource underneath (Kangle, 1986). Partly influenced by the Jaina and Buddhist traditions and partly driven by the expansionist requirements, the state over-ruled caste barriers and allowed the tribal and lower caste people to independently serve army, agriculture and technical crafts (*AS.* 1.3.8 and 9.2.24).

After the collapse of the Maurya power (187 B.C.), two important political changes came about in India: the rise of the brahmanic and revivalist dynasty of the Sungas, and the intrusion of the Bactrian Greeks. The Suṅgas made the caste barriers more rigid, and initiated feudalism in India by giving land grants to the brahmans and the upper caste people (towards the end of the second century B.C.). This was the period of the compilation of the *saṃhitās* named after Manu and Yājñāvalkya; it also witnessed the rise of private ownership and diversification of trade, probably on account of the strengthening of hereditary caste structure.

The *Milinda-pañha* (The Questions of Milinda or Menander of Sialkot) of this period enumerated 75 occupations of which sixty involved various kinds of crafts. Eight crafts related to separate metals, minerals and precious stones. A variety of brass (*ārakūṭa*), zinc, antimony and red arsenic were mentioned (*Milinda - pañha*, 2.106).

Sifting through the epigraphic records of this period (200 B.C. - 100 A.D.) obtained from western Deccan, Buddhist sites of Bharhut, Sanci and Mathura, Chakravarti came across and compiled (Chakravarti,1991,pp.305-350) the

following list of professionals: carpenter, bamboo-worker, reed-maker, brazier, potter, weaver, cloth-maker, dyer, oilman (extractor of oil from vegetable seeds), garland-maker, perfumer, jeweller, ivory- worker, sculptor, goldsmith, blacksmith etc.; most of the professionals had guilds or banking systems in urban areas. Evidently, caste injunctions could not stifle Indian technology although it imposed barrier to the necessary diffusion of knowledge.

(D) Five Centuries After Christ

The Christian era started in India with the transition from the Greek to Roman and Graeco-Roman influences. Whereas the Greek (and then Scythian, Parthian, Kuṣāṇa and later Hun and Muslim) intrusions were land-based and came through the West and North- West of the sub-continent, the Roman contact was sea-based and initiated in the southern and western part of the Deccan.

Several centuries earlier, the Mauryas had taken iron plough- share to the South and initiated large scale agriculture and urbanization. Patañjali of the Suṅga era described how the crude beryl mineral was being mined in he Valavaya mountains and brought to the city of Vidura (near Mysore) for processing (*Mahābhāṣya*, on *Aṣṭadhyāyī* 4.3.84). Mathura had acquired special celebrity for its manufacture of *śataka*, a special kind of cloth, but it was yet to become a transit centre for silk goods to be transmitted to the south and west Deccan and then to Rome.

The Roman empire had an abiding interest in the Chinese silk and the Indian spices, precious gems, steel etc. but the Parthians of Iran provided considerable obstacles for the direct Roman trade. This barrier was removed when Hippalos discovered (before 14 A.D.) monsoon trade wind for direct trade with south India; the Buddhist Kuṣāṇas and Śātavāhanas (of Andhra Pradesh, also ruling over the western Deccan) collaborated with the Romans and allowed a new silk route through Mathura, Ujjaini and the port of Barygaza. Mathura rapidly became a transit trade centre, also promoting various new crafts like silk weaving, sculptural arts, brass casting and so on. The diamond mine of Eastern Malwa were exploited by the Kuṣāṇas and later the Scythians during the Ist-2nd century A.D. (Mukherjee, 1970). Though invaders, they gradually integrated themselves into the cultural mainstreams in India.

The south Indian empires (the Colas, Ceras etc.) engaged in profitable trade on precious stones with the Romans. Pearl, sapphire, carnelian, ruby, beryl were some of the gems processed and exported by India; coral, emerald etc. used to be imported. Naturally gemmology was developed as a subject in several scholarly texts of this era and the art of jewellery promoted by a widespread and vigorous trade.

The present author has discussed elsewhere (Biswas, 1994) how beryl and emerald trade played significant roles in the history of ancient India; very significantly, many hoards of Roman gold coin have been unearthed near the beryl-producing sites.

Following the Maurya traditions, the Śātavāhanas of the Deccan levied taxes on different crafts being organised by respective well-formed guilds. The empire gave considerable land grants to the Buddhist monasteries. Both the guild and monastery

establishments assisted the royal administration in many ways (Ray, H.P., 1986). Nagarjuna, the famous Buddhist monk and alchemist, introduced to the Satavahana empire during the end of the second century A.D., the then brass technology which existed in Rajasthan and Gujarat (Biswas, 1993). Nagarjunakonda became the capital of the Ikṣvākus during 225-330 A.D. and patronised diverse arts and crafts. Many excavated sites on the Krishna delta of this period showed urban dimensions and Buddhist association. The town of Satanikota on the Tungabhadra used burnt brick and patronised a flourishing bead industry.

There were two active textile centres in the Central Deccan, namely Tagara (Ter) and Paithan (Pratiṣṭhāna, the Sātavāhana capital). Excavations at Ter have yielded a number of vats for dyeing cloth. Similar vats were found at Arikamedu (near Pondicherry, Tamilnadu). A brick-built dyeing vat has been unearthed at Uraiyur a suburb of Tiruchirapalli town in Tamilnadu. These structures belonged to the Ist-3rd centuries A.D. and signified vigorous national and international trades.

Chakravarti discussed (Chakravarti, 1991, pp. 305-350) the process of urbanization in south India during this period, and admitted that the existence of agricultural surplus in the neighbourhood was a necessary but not sufficient condition. The emergence of a strong political power such as the Śātavāhanas and the opening of trade routes were also crucially important in urbanization and the growth of technology. The coastal towns could not grow to such large proportions without the Indo-Roman trade. Such a port was known to the Romans as *emporion* or 'an oriental market-town on the sea-coast'. There developed a cluster of emporia such as Barygaza or Bhrigukaccha (Broach), Muziris (Cannanore), Kaveripattinam, Poduce (Pondicherry) etc. Graeco-Roman merchants were present in these sites witnessing production of polished stones, bead, imitation glass, jewelleries and textile products. Many of these manufacturing centres dwindled after the collapse of the Indo-Roman trade.

The southern and northern cities of the era were mostly terminal and transit trade centres. Sirkap establishment in Taxila and Ahicchatra in the Bareilly district flourished as trade centres with improved road communication. The 2nd-3rd century A.D. edition of the epic *Mahābhārata* mentioned (2.28.49-50) 'trade links with Rome through Bhrigukaccha'!

R.S. Sharma has discussed the trends in the economic history of Mathura up to the period of 300 A.D. (Sharma, 1983, pp. 170-183). One of the best cities in the sub-continent during its time, Mathura grew essentially as a transit trade centre during the Scytho-Parthians and the Kuṣāṇas, and under the umbrella of Buddhism rather than the Kṛṣṇa-cult which flourished later under the Guptas. Its strategic position on the trade routes connecting the east, the north-west and the south-west contributed to its development as the centre of many technologies - cotton-weaving (*śāṭaka*), silk-weaving, sandstone, spice, sculpture, glass, metalsmith industries particularly iron, steel and brass, goldsmith, NBP ware, baked tile, lime-mixed brick concrete etc. During the first five centuries of the Christian era the money economy was in full swing in India, as evident from the gold coins of the Romans and the Kuṣāṇas, the Kuṣāṇa copper, Śātavāhana lead coins or potin and lastly the Gupta era gold coins.

The Gupta period was the second golden age in ancient India after the Mauryas. Although it spanned nearly one and half century (Candragupta I's ascension on the throne 320 A.D. and the end of Skandagupta's reign 467 A.D.), the kingdom was not as widespread as the Maurya empire. The first seventy years of the reign were spent in fighting with the Scythians (who were finally defeated by Candragupta II in 388 A.D.), and the empire ultimately collapsed with the second Huna invasion in 495 A.D.

The fourth to fifth centuries A.D. witnessed the compilation of the encyclopaedic works on materials, metals, minerals, gems, textiles and other industrial products. The texts such as *Aṅgavijja*, *Amarakośa*, *Bṛhatsaṃhitā* of Varāhamihira, the various Ratnaśāstra texts, etc. were compiled during this period, bearing witness to the prolific diversification of the crafts and trade.

Much of the glory of the material cultures during the Maurya, Śātavāhana and the Gupta eras were due to the Graeco-Roman contacts which not only promoted trades and crafts but also enlightened the Indians through inflow of novel and at times scientific ideas. The Sanskrit words *kastira* (tin) and *arakuṭa* (brass) were derived from the Greek *cassiteros* and *oreichalkos* respectively. The Persians, Greeks and Romans were the first patrons of Indian iron, steel and brass. There was considerable Greek influence bearing upon the post-Christian era sculpture (on stones and metals) in India.

Yavaneśvara was a contemporary of the Scythian king Rudradaman. His Greek book (150 A.D.), translated into Sanskrit one century later, discussed various *dhātus*: *dhāmya* (bright) and *adhāmya* (dull) (Pingree, 1978). Significantly, the first category included steel, and the second *rasaka* or zinc ore, both of contemporary importance. While postulating the geological theory of the origin of gems (*Bṛhatsaṃhitā* or BS. 80.3) and demolishing the age-old Rahu theory of eclipses (*BS*. 5.13), Varāhamihira acknowledged the wisdom of Graeco-Roman scholars (*BS*. 2.32). Many Greek words were assimilated in the Indian texts on mathematics and astronomy. At the same time, Āryabhaṭa showed his original mathematical prowess a millennium before Newton.

(E) The Issue Of Medieval Decadence -

The transition between the 'ancient' and the 'medieval' period has been tentatively placed at 1200 A.D. The choice is however rather arbitrary; it has been suggested that one could think of medieval decadence having set in with the collapse of the Gupta empire (467 A.D.), death of Harṣavardhana (647 A.D.) the Muslim conquest of part of India (10th century) or its consolidation (1200 A.D.). While R.S. Sharma prefers the earlier dates (Sharma, 1983), H.C. Ray insists on the later dates (Ray, H.C., 1931-36).

As a matter of fact, there is no single sharp transition date. The forge-welding tradition, exemplified in the Delhi Iron Pillar (fourth century A.D. Gupta Period), was continued for many centuries afterwards - vide the Orissa iron beams at Bhuvaneswar (7th century), Konarak (9th century), the famous Dhar (near Indore) pillar of King Bhoja (1000-1055 A.D.), 'the largest in the ancient world' etc. The brass technology of ancient India was invigorated in the 13th century Zawar (near

Udaipur, Rajasthan). The bronze technologies of Bengal and Bihar (8th-9th centuries) and of Tamilnadu (9th - 13th centuries) were linked with the supply of tin and gold from, and extensive trade contacts with South-East Asia. The glory of the Indian mathematics and astronomy, hailed by Severus Sebokht (662 A.D.), had been initiated by Āryabhaṭa (born 476 A.D.) and Brahmagupta (598 A.D.), and later sustained by Lalla (748 A.D.), Mañjulā (932 A.D.), Śrīdhara (1020 A.D.), Bhāskarācāryya (born 1114 A.D.) etc. In other words, the flame of ancient Indian science and technology never died, it went on flickering.

On the other hand, some decadence had set in, and although Sharma puts the 'transition' at the demise of the Gupta empire, many symptoms of decay had been evident much earlier. The Suṅgas and the Sātavāhanas had introduced the system of land grants to the Brahmanic and the Buddhist world respectively. This practice was continued during the Gupta era. The late Gupta kings and the Vākāṭaka kings (5th century A.D.) not only gave away whole villages to the brahmans, but also surrendered the rights for administration and underground mineral resources. The feudal land-lords indulged in lease cultivation through landless exploited labourers. Often the cultivable lands were further fragmented and there was no effort for more efficient large-scale or collective farming. With the irresponsible middlemen in between, the state loosened its control over the masses and their welfare. The new feudal class could exploit the masses but had no responsibility to better their lot. Unlike Europe, India did not have a sharply defined class of feudal barons organised in councils and assemblies (Sharma, R.S. 1983, pp. 145-157, Section on Feudal Beginning).

Ever since the *Manu Saṃhitā* period of the Śuṅga dynasty, the caste system became gradually more repressive. After the third century A.D., the land grant system further accentuated it. The brahman landowners inducted tribals and *śūdras* for tilling and thus created deep tension with the *vaiśya* community who had the monopoly of agriculture during the earlier periods (Sharma, R.S., 1983). Many castes and sub-castes were invented.

The insular attitude in India resulted in over- compartmentalisation of technology. The Hindu law-makers distinguished between metal-workers and smelters (Sharma, R.S., 1983). Only specific tribes (later equated as castes) like *muṇḍās* practised iron-making (hence the term *muṇḍaloha*), *bhils* zinc- making, *turis* gold and diamond-washing, *kansaris* bell-metal trading and so on. The different castes, practising different aspects of trade, rarely exchanged informations, only which could result in a faster growth of science and technology in India.

Basham has described the post-Gupta era in ancient India as 'the twilight of Hindu independence', the history of the centuries after the Gupta era being 'a rather drab story of endemic warfare between rival dynasties' (Basham, 1954). Sharma describes this age as 'the period of military camps or '*jayaskandhavāras*', with marketisation reaching a low ebb, money- supply dwindling and continuing decay of urbanism and technology.

Social Factors Underlying the Decay of Ancient Indian S & T

The present author had discussed this issue in detail elsewhere (Biswas, 1969, first two chapters, Biswas, 1988), and recorded his major agreements and disagreements with Chattopadhyaya's paradigm (Chattopadhyaya, 1986).

Chattopadhyaya had shown in his famous book *Lokāyata*, how much theoretical materialism there had been in ancient India, and how it had been systematically obscured and vilified by the theologians (Chattopadhyaya, 1959). He extended his thesis ably, by explaining what is living and what is dead in Indian philosophy (Chattopadhyaya, 1976), and then making an incisive study on ideology and counter-ideology in the ancient Indian science (Chattopadhyaya, 1977). P.C. Ray attributed the decline in the scientific spirit in India to the entrenchment of casteism in the society and the stranglehold of the priestcraft and anti- materialist philosophy (Ray, P.C., 1902-03, pp. 192-197). We have supported this analysis earlier (Biswas, 1969; Biswas, 1988) as well as in this paper.

The present author has endorsed Chattopadhyaya's basic thesis of a dialectical struggle between reason and anti-reason in the Indian thought-world *with the rider* that this struggle existed in all civilizations, and exists even to-day down to the psychological plane of an individual (Biswas and Biswas, 1989; Biswas, 1988). Thus Brahmagupta calculated the diameter of the moon in order to explain its eclipsing the sun, and yet gave tacit approval to the Rāhu theory of eclipses. The *Rasa-Ratna- Samuccaya*, a 13th century A.D. text, strongly endorsed accurate and careful experimentation, and yet strangely endorsed the view that free diffusion of knowledge was not desirable.

We disagreed (Biswas and Biswas, 1989) with Chattopadhyaya's paradigm (Chattopadhyaya, 1986) when he grossly undervalued the Vedic tradition, subscribing to the myth of Aryan intrusion into India, and suggesting that the credit for early science in India goes to the Indus valley people rather than the Rgvedic culture - as if the two were not contemporaneous and not part of a wider civilization. In the two volumes of his recent work (Chattopadhyaya, 1986; Chattopadhyaya, 1991), his consistent thread of argument has been that all the reason in ancient Indian science was borrowed or derived from non-Vedic sources and the Vedic literature had the monopoly of anti-reason. His Marxist protest against the extreme and oft-uttered expression ....'the Vedas contain all knowledge' was carried to the opposite extreme position and is untenable. Even Joseph Needham cautioned in his Foreword to the book by Chattopadhyaya (1986) that one 'must beware of pouring out the baby with the bath-water'.

To counter the biased and one-sided view of Chattopadhyaya, we may cite the balanced opinions of Mahadevan (1969) and Pande (1969). Mahadevan asserted that the orthodox systems such as Nyāya-Vaiśesika, Sāṅkhya-Yoga did make use of scientific concepts without defying the Vedic tenets. Caraka accepted scientific methodology (including observation and logic) as well as *Iśvara* (God); so did Newton. The Vedic orthodoxy might have extinguished Lokāyata literature (as alleged by Chattopadhyaya) but was not that powerful to curb the two others, almost equally old, heterodox anti-Vedic systems — Buddhism and Jainism. How could the decline of Indian science be attributed to the Vedic orthodoxy alone? Pande

(1969) concluded that none of the Indian philosophies - orthodox or heterodox - were anti-reason or anti- science. Of course, the intellectual philosophers (even the proponents of Lokāyata) contributed more to speculation rather than mechanical inventions and technology. Yet there was no obstacle against the phenomenal growth of medicine, metallurgy, mathematics and astronomy in ancient India.

In his masterly treatments on history of science and technology in *ancient* India, Chattopadhyaya often jumped into the *modern* period castigating 'Hindu revivalism', and the phoney proponents of Vedic science in the modern era (Chattopadhyaya, 1986, pp. 17-20, 24-25, 398-402; Dasgupta, A. 1987)[2] - entirely by-passing the medieval period, the millennium of Muslim invasion, colonialism and fundamentalism. Such an act of omission and commission emboldened a British reviewer of his latest book (Chattopadhyaya, 1991) to hold Hindu obscurantism to be solely responsible for the decline of Indian science (Robert Temple, 1991)[3].

A much more balanced picture was presented by Āl-Bīrūnī, the brilliant Muslim scholar of the eleventh century (Sachau, Reprint, 1983) quoted in one of our earlier books (Biswas, 1969, pp. 20-22). While criticising the Hindus to be 'haughty and foolishly vain', Al-Bīrūnī was full of praise for the mathematical and scientific abilities of the Hindu scholars, some of whom were 'enjoying the help of God' or 'inspired by God'. According to him, the Hindus preceding his era had been broad-minded. Again, in his own words :

"Mahmud utterly ruined the prosperity of the country, and performed there wonderful exploits, by which the Hindus became like atoms of dust, scattered in all directions. The Hindu sciences have fled to places where our hands cannot yet reach. Their scattered remains cherish of course, the most inveterate aversion towards all Muslims".

The barbarity of the early Muslim invaders in India shocked even the Arab and Persian intellectuals. Shaikh Bu Ali Sina, a respected physician and biologist, refused to come to India with Mahmud, whose plunder and loot, he felt, was destroying Indian science. These facts were ignored by P.C. Ray and Debiprasad Chattopadhyaya, while commenting on the decline of the Indian science, even though their predecessor Pramatha Nath Bose had deliberated on the Muslim as well as the British colonialism affecting the scientific performance of the Indians, and the Hindus in particular (Bose, P.N. 1975)[4].

Although our narrative ends with the demolition of the Odantapuri monastery and its library by the Muslim invaders in 1199 A.D., we cannot help recording that the earlier Indian (Hindu) science and technology survived very well beyond 1200 A.D. The iconoclasts burnt the books but could not destroy knowledge, destroyed and melted the icons but could not annihilate the arts and science of the icon-making tradition. It has been internationally recognised that the Hindu India was not only the first in the world to produce pure zinc by distillation, but also the first to produce it (and high quality brass) on a large manufacturing scale at Zawar, Rajasthan (Biswas, 1993). The Muslim invaders could not gain access to the well-guarded secret or the technical know-how regarding zinc for many centuries. We expected that Chattopadhyaya would have considered these points and 'his views might have come closer to ours (Biswas and Biswas, 1989, p. 198)[5].

In our early treatise we identified that political instability, lack of ideological motivation and necessary political will to transform and modernise a society, and gross socio-economic inequality had largely contributed to the stagnation of scientific progress in many developing countries including India (Biswas, 1969; Biswas and Biswas, 1989, p. 198). In conclusion, we may assert that there was nothing radically different or wrong in the ethos of ancient India. Whenever the natural intellectual talent of the Indians received nourishment from the conducive socio-political factors - such as economic challenges and opportunities, ideological motivation, political stability, contact with the outside world, stimulating but not overwhelming etc.-the Indian science and technology prospered. The vitality of this ancient tradition is attested by the fact that it could not be totally extinguished either by the Hindu obscurantism, Muslim fanaticism or the British colonialism.

Notes

1. *In pages 27 and 52 of "History of Science and Technology in Ancient India", Chattopadhyaya has unkindly criticised "Concise History of Science in India" (INSA publication) as providing 'a false model of catalogue-making'. One should understand the importance of collecting, collating and cataloguing newly emerging facts which might alter earlier paradigms.*
2. *Dasgupta (1987), one of the reviewers of this book, wrote in the Statesman, that "perhaps we may have been spared the careful consideration of the views of Maharshi Mahesh Yogi".*
3. *Robert Temple (1991) reviewed the latest work of Chattopadhyaya and wrote:*

   "Chattopadhyaya shows that the history of Hindu obscurantism has suppressed the rise of science in India through the ages - the implications for the present are clear... The smug self- satisfaction of the devout - and they nearly won a recent election - has put a wet blanket over generation after generation of brilliant men of science".

   Contrasted with Āl-Bīrūnī's balanced analysis, this is indeed high politics and low scholasticism.
4. *Vol. III 'Intellectual Conditions' ("A History of Hindu Civilisations during British Rule", by P.N. Bose) deals with the influences of the Muslim invaders (pp. 33-38, 128-135), the British rule etc. on Indian Science, among other topics.*
5. *Our expectation could not be fulfilled on account of Chattopadhyaya's untimely death in May 1993.*

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